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TELEVISION.*

BY

DR. V. K. ZWORYKIN, E.E., Ph.D.,

Research Division, RCA Victor Company, Inc., Camden, N. J.

SYNOPSIS.

This paper gives an outline of a new television system developed in the laboratories of RCA Victor Company, in Camden, N. J.

The system is truly electrical and employs only electronic devices, without a single mechanically moving part.

The translation of the visual image is accomplished by means of a vacuum tube called the iconoscope. This tube is a virtual electric eye and consists of a photo-sensitive mosaic corresponding to the retina of the human eye, and a moving electron beam representing the nerve of the eye. The image is projected optically on the mosaic and transformed within the tube into a train of electrical impulses, representing the illumination of individual points of the image.

The reproduction of the image is accomplished by means of another vacuum tube, the kinescope, which transforms the electrical impulses back into the variation of light intensity through the bombardment of a fluorescent screen by the moving electron beam.

The movement of the electron beams in both tubes, which is responsible for both transformations, is linear and divides the picture into a series of parallel lines. The movements are synchronized so that the instantaneous position of the beams with respect to a point in the picture is always identical. The synchronization is transmitted together with the picture signals, and operation of the receiver is completely automatic.

The sensitivity of the iconoscope, at the present time, is approximately equal to that of a photographic film operating at the speed of a motion picture camera, permitting the transmission of outdoor scenes. The resolution is high, much higher than necessary for television images of the highest quality.

The paper describes the theory of the system, its characteristics, mode of operation, and includes photographs of images obtained on the fluorescent screen of the receiver.

* Presented at the Stated Meeting held Wednesday, October 18, 1933.

INTRODUCTION.

"Television" has become a familiar word in recent times and conveys to us the idea of an artificial reproduction of transient visual images. Since it is artificial, we cannot expect to have an absolutely perfect reproduction of the original, and therefore, for better definition, the word "television" itself requires an additional adjective to identify the degree of perfection.

It is an accepted practice in reproducing pictures in printed matter, such as books and newspapers, to resolve the picture into a number of dots. The definition of the picture is then identified by the number of dots to a square inch. An ordinary picture may contain 4000 picture elements, or approximately 65 lines per linear inch, while for finer works a larger number is used. Similarly, in television, due to the requirement of transmission by one channel, the picture is dissected into a number of elements, which are transmitted in succession, one element after another in a series of parallel lines. It has, therefore, become quite common to refer to the reproduction in terms of lines. Thus we speak of 30, 60 or 120 line television, which means that the whole reproduced image is composed of 30, 60 or 120 lines, each line varying in density throughout its length.

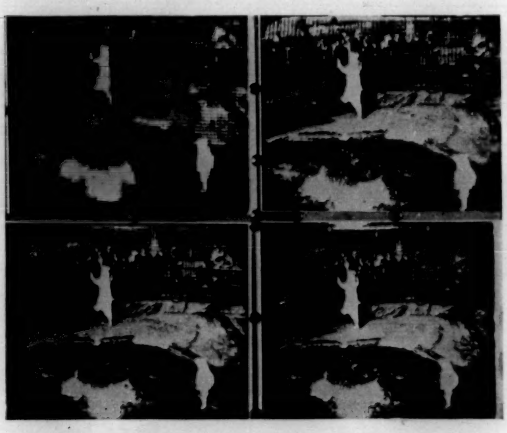
The greater the detail is, the more difficult is the solution of the television problem; it is very important to determine accurately how far the compromise can be carried without affecting the quality of the reproduced image. In other words, what is the minimum number of lines in the television picture with which the reproduced image can be accepted as satisfactory?

A number of excellent works have already been published on the subject, both from the theoretical and experimental points of view.[1] The results of these works agree quite accurately, and predict that the increase in the number of lines at first gives a great increase in definition, then the rate of

[1] William H. Wenstrom, "Notes on Television Definition," *Proceedings I. R. E.*, September, 1933, Vol. 21, No. 9, p. 1317. Selig Hecht and Cornelis Verrijp, "The Influence of Intensity, Color and Retinal Location on the Fusion Frequency of Intermittent Illumination," *Proc. Nat. Academy of Science*, Vol. 19, No. 5, p. 522. E. W. Engstrom, *Proceedings of I. R. E.*, December, 1933.

increase slows down and finally approaches a certain saturation value, after which a further increase in the number of lines gives a negligible increase in the definition of the image.

FIG. 1.



In order to give a better idea of this relation, Fig. 1 [2] shows a comparison of four reproductions of the same picture made by 60, 120, 180 and 240 lines, respectively. These pictures are made not by television, but by special optical methods, and do not contain the distortions which are possible during various transformations involved in the process of television. Therefore, they should be regarded as an optimum for television reproduction. This set of pictures indicates that for an image with a great deal of detail, we should regard 240 lines as a minimum. For a picture with less detail, these requirements can be somewhat lower, as can be seen clearly from Fig. 2. Both these examples are given for half-tone reproduction. The black and white picture requires approximately the same number of lines for the corresponding definition, as shown on Fig. 3.

[2] Courtesy of Mr. E. W. Engstrom.

FIG. 2.

FIG. 3.

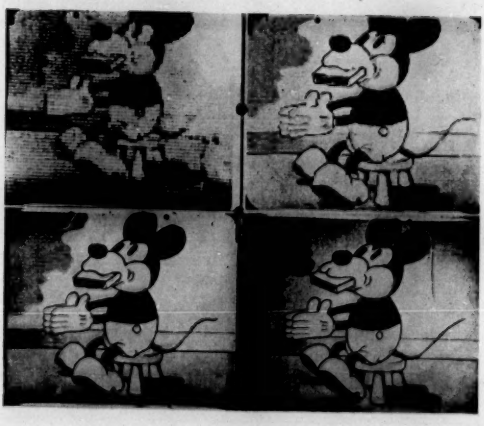
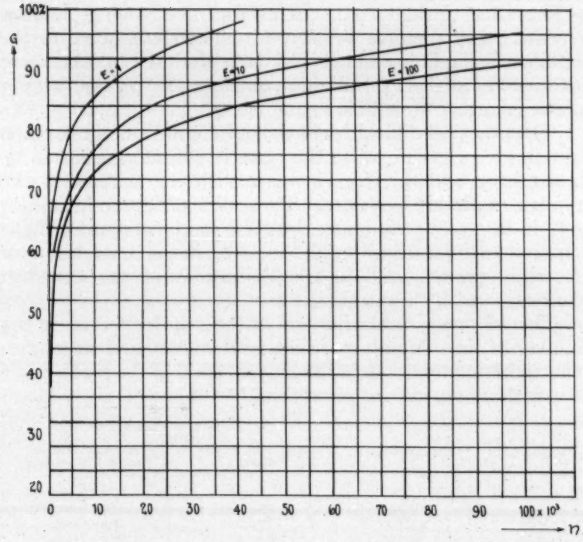


FIG. 4.



This relation between the definition and the number of lines can also be shown by a curve, such as in Fig. 4.[3] This curve is obtained theoretically from the resolution of the human eye and is represented by the expression,

$$G = \rho \log n,$$

where G is the definition of the picture,

n—the number of picture elements,

and ρ—coefficient depending on the size of the picture and the viewing angle.

The three curves are for three different intensities of the illumination of a picture of 1, 10 and 100 lumens. All these relations are considered for a still picture. Television pictures

[3] J. A. Ryftin, *J. Zeitschrift für Technische Physik*, Band III, Heft 2–3, 1933.

of moving objects give better resolution for a smaller number of lines, due to the fact that television, like moving pictures, repeats many pictures per second. Therefore, some of the details missing in one image may be reproduced in others and integrated by the eye, as one combines the picture with a greater number of details.

The practical difficulties in the development of a television system are proportional to the quantity of information to be transmitted and therefore increase with the increase in the number of picture elements. These difficulties are found not only in dissecting the image, but also in the amount of light required at the transmitter and receiver, in the construction of electrical circuits, and in the limitations of the electrical channels used for transmission.

The following table illustrates the relation between the number of lines, number of picture elements, and maximum picture frequency assuming the aspect ratio of the picture as 3 to 4 with 24 repetitions per second.

Scanning Lines.	Picture Elements.	Maximum Picture Frequency.[4]	Maximum Picture Communication Band.
60	4,798	63,970	127,900
120	19,200	256,000	512,000
180	43,190	576,000	1,152,000
240	76,780	1,024,000	2,048,000

[4] 10 per cent. is added to compensate the loss of time for synchronizing signals.

The width of communication band for pictures with over 100 lines definition makes impossible the use of radio channels of frequencies utilized for sound broadcasting. The only solution for transmission of these pictures, therefore, lies in ultra-high frequencies. The communication, however, is a separate subject which will not be discussed in this paper. Also, it is not the intention of this presentation to give a history of television development. It is sufficient to say only that practically all the previous work was done with mechanical methods as a means of scanning or resolving the picture into picture elements for transmission. Likewise, mechanical methods were employed at the receiver to reconstruct the picture from the transmitted elements. This involved purely mechanical complications in construction of

sufficiently precise scanners, and difficulties in increasing the number of picture elements and particularly in obtaining sufficient light. This last limitation actually introduced a stone wall which prevented the increase of resolution in the transmitted picture necessary to obtain the desired quality and practically excluded all hope of transmitting an outdoor picture—the real goal of television.

To understand the reasons for this difficulty, we should remember that the picture is scanned point by point, and, therefore, that the photo-sensitive element is affected by the light from a given point only for a very short interval of time corresponding to the time of illumination of one picture element. Assume for a picture of good quality we desire 240 lines, or 76,000 picture elements. For twenty-four repetitions per second, this means that the time of transmission of one picture element is 1/1,824,000 of a second. On the other hand, the output of the photocell to the amplifier is proportional to the intensity of the light and time during which the light is acting on the photocell. A brief computation shows how microscopic will be the output of the photocell for this number of picture elements. If we take an average photographic camera with a lens F–4.5, the total light flux falling on the plate from a bright outdoor picture is of the order of 1/10th of a lumen. Substituting a scanning disc suitable for 76,000 picture elements for the plate and using a photocell of 10 micro-amperes/lumen sensitivity, we will have a photo current from a single picture element

$$I_e = \frac{I \times 10^{-5}}{10 \times 76{,}000} = 1.3 \times 10^{-11} \text{ amp.}$$

The charge resulting from this current in the time of one picture element is

$$Q = I \times t = \frac{1.3 \times 10^{-11}}{1.824 \times 10^{6}} = .7 \times 10^{-17} \text{ coulombs.}$$

Comparing that with the charge of one electron,

$$e = 1.59 \times 10^{-19} \text{ coulombs,}$$

we see that only 44 electrons are collected during the scanning

of one element. The amplification of such small amounts of energy involves practically insurmountable difficulties.

If we now compare this condition with that of a photographic plate during exposure, we will see that the latter operates under much more favorable conditions, since all its points are affected by the light during the whole time of exposure. This time for studio exposure is several seconds, and of the order of one hundredth of a second for outdoor exposures, or many thousand times greater than in the case of an element in the scanned television picture. The human eye, which we regard as an ideal of sensitivity, operates also under the same favorable condition.

If a television system could be devised which would operate on the same principle as the eye, all the points of the picture would affect the photo-sensitive element all the time. Then in our example of a picture with 76,000 elements, the photoelectric output for each point would be 76,000 times greater than in the conventional system. Since scanning is still necessary in order to use only one communication channel, we should have some means for storing of the energy of the picture between two successive scannings of each point.

The light requirement and necessity of avoiding the mechanically moving parts resulted in the development of an entirely electrical television system, employing special electronic devices for both transmission and reception.

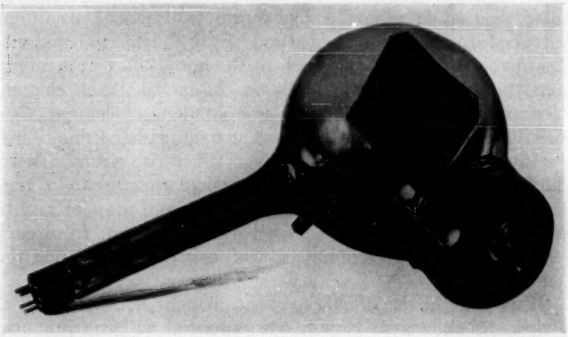
ICONOSCOPE.

On the transmitting end this device took the form of a virtual artificial electric eye. The device was named iconoscope, the name being derived from two Greek words signifying "image observer." The photograph of this device is shown on Fig. 5.

It consists of two principal parts enclosed in an evacuated glass bulb. The first part is the photo-sensitive mosaic, consisting of a metal plate covered with a great number of miniature photo-electric cells, insulated from the plate and each from the other. The function of the mosaic is similar to that of the retina of the eye. It transforms the energy of the light from the image into electrical charges and stores them until they can be transformed point by point into electrical

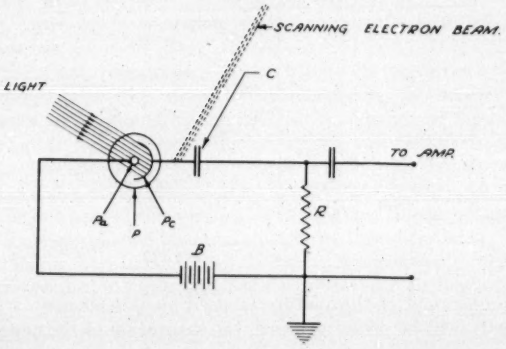
impulses and transmitted. This transformation is accomplished by an electron beam scanner, the nerve of this electric eye.

FIG. 5.



To complete the analogy of the iconoscope with the human eye, we shall mention that it possesses an electrical memory, because with a good dielectric the charges of the mosaic can be preserved for a considerable length of time.

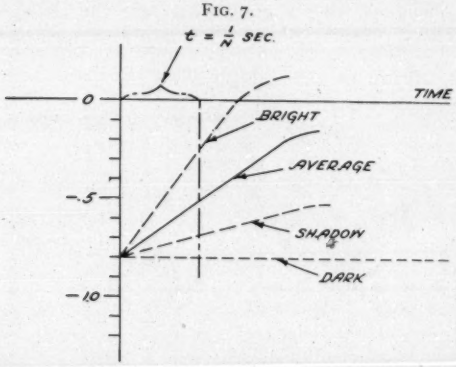
FIG. 6.



To fully understand the operation of the photo-sensitive mosaic of the iconoscope, it is best to consider the circuit of a single photo-electric element in the mosaic, as shown in Fig. 6. Here P represents such an element, and C its capacity to a plate common to all the elements, which hereafter will be called the "signal plate." The complete electrical circuit can be traced starting from the cathode P_e to C, then to resistance R, source of e.m.f. B, and back to the anode P_a. When light from the projected picture falls on the mosaic, each element P_e emits electrons, and thus the condenser element C is positively charged by the light. The magnitude of this charge is a function of the light intensity. When the electron beam which scans the mosaic strikes the particular element P_eC that element receives electrons from the beam and may be said to have become discharged. This discharge current from each element will be proportional to the positive charge upon the element.

If we plot the rise of charge of the element P_eC with respect to time, as shown on Fig. 7, the potential will continuously increase due to the light of the picture. The slope of this increase or dv/dt will depend only on the brightness of the

FIG. 7.



particular part of the picture focused on this element. This linearity will be preserved until the saturation of the capacity

C, which is so chosen as never to be reached at a given frequency N of repetition of the discharge. Since the scanning is constant, the interval of time, t, which is equal to $1/N$, is also constant and therefore the value of charge depends only on the brightness of this particular point of the picture. With constant intensity of the scanning beam, the impulse through R, and consequently the voltage drop V_I across R, is also proportional to the brightness of a given point of the picture. This potential V_I is the output of each single photo-element of the iconoscope, which is applied to an amplifier.

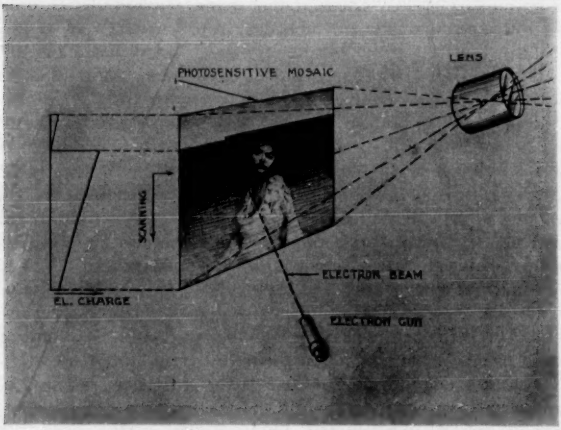
The above explanation is actually somewhat complicated by the fact that this discharging beam not only neutralizes the positive charge of the photo-element, but charges it negatively. The equilibrium potential of the element is defined by the velocity of the beam and the secondary emission from the photo-emitting substance due to bombardment by the electrons of this velocity. This equilibrium condition in the dark, for a normal iconoscope, is of the order of .5 to 1.0 volts negative. The light causes the element to gain a positive charge, thus decreasing the normal negative charge, and the scanning beam brings it back again to the equilibrium potential.

Another complication is due to the existence, besides the discharge impulses from the individual elements, of a charging current due to light on the whole mosaic. This current is constant for a stationary picture but varies when the picture, or part of it, begins to move across the mosaic. This variation, however, is very slow and does not affect an amplifier which has a cut-off below 24 cycles.

Figure 8 gives an idea of conditions on the surface of the mosaic. Here the shaded picture represents the electrical charges accumulated by the individual elements of the mosaic due to the light of the projected image. Although the background of this image is of uniform density, the corresponding charges at a given instant are not uniform but vary, as shown on the left part of this picture. The highest charge occurs just before the exploring beam has discharged the elements. After the beam has passed the charge is momentarily near its equilibrium condition and begins to increase throughout the whole scanning period, attaining its maximum value again just before the scanning by the beam.

The electron beam, in neutralizing the charge of a particular point of the picture, releases practically instantaneously the energy stored there during the whole 1/24th of the second.

FIG. 8.

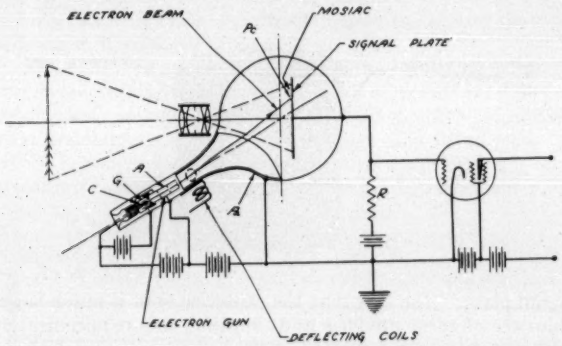


The electrical impulse created on the opposite side of the mosaic energizes the amplifier. The magnitude of this impulse is greater than the corresponding impulse, produced by a system not utilizing the storing effect, in ratio of time intervals during which the light from the picture point acts on the photo-sensitive element. In this case, it is equal to the number of picture elements, or 76,000 times as great. This is true, assuming that the device has 100 per cent. efficiency. This, however, is a practical impossibility due to various losses, and at the present we have to satisfy ourselves with only about 10 per cent. of the possible gain.

The schematic diagram of a complete electrical circuit for the iconoscope is shown in Fig. 9. Here the two parts of the photo-element *P*, shown on Fig. 6, are entirely separated. The cathodes are in the shape of photo-sensitive globules on the surface of the signal plate and insulated from it. The

anode or collector is common and consists of a silvered portion on the inside of the glass bulb.

FIG. 9.

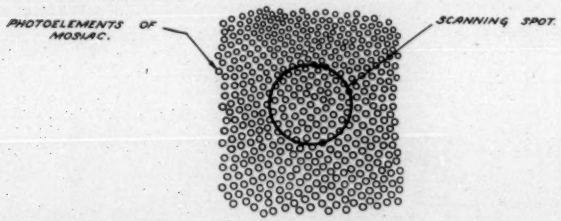


The capacity C of each individual element with respect to the signal plate is determined by the thickness and dielectric constant of the insulating layer between the elements and the signal plate. The discharge of the positive charge of the individual elements is accomplished by an electron beam originating in the electron gun located opposite the mosaic and inclined at 30° to the normal passing through the middle of the mosaic. Both mosaic and electron gun are enclosed in the same highly evacuated glass bulb. The inclined position of the gun is merely a compromise in the construction in order to allow the projection of the picture on the surface of the mosaic.

The resolution of the iconoscope is determined by both the size and number of picture elements in the mosaic, and the size of the scanning electron beam. In practice, however, the number of individual photo-elements in the mosaic is many times greater than the number of picture elements, which is determined entirely by the size of the scanning spot. This is shown diagrammatically on Fig. 10. From the initial assumptions formulated in the analysis of the ideal circuit for individual elements, as shown on Fig. 6, we find the qualifica-

tions which should satisfy the mosaic for the iconoscope. These assumptions required that all the elements be of equal size and photo-sensitivity and equal capacity in respect to the

FIG. 10.



signal plate. The fact that the exploring spot is much larger than the element modifies and simplifies this requirement so that the average distribution, surface sensitivity and capacity of elements over an area of the mosaic corresponding to the size of the scanning spot should be uniform. This allows considerable tolerance in the dimensions of individual elements.

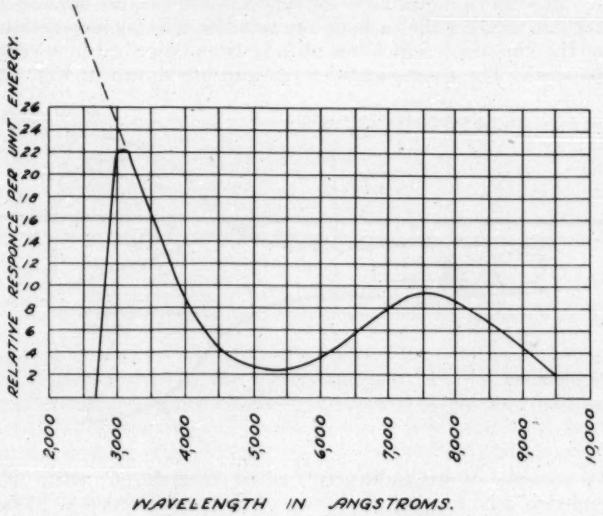
The requirement of uniformity, which at first glance appears quite difficult to obtain, is solved by the help of natural phenomena. It is known that such a common material as mica can be selected in a thin sheet of practically ideal uniform thickness and it therefore serves as a perfect insulating material for the mosaic. The signal plate is formed by a metallic coating on one side of the mica sheet. The mosaic itself can be produced by a multitude of methods, the simplest of which is a direct evaporation of the photo-electric metal onto the mica in a vacuum. When the evaporated film is very thin it is not continuous but consists of a conglomeration of minute spots or globules quite uniformly distributed and insulated each from the other. Another possible method is that of ruling the mosaic from a continuous metallic film by a ruling machine.

Although the initial method of formation of the photo-sensitive mosaic was the deposition of a thin film of alkali

metal directly on an insulating plate, subsequent developments in the photocell art resulted in changes in the methods of formation of the mosaic. The mosaic which is used at present is composed of a very large number of minute silver globules, each of which is photo-sensitized by cæsium through utilization of a special process.

Since the charges are very minute the insulating property and dielectric losses should be as small as possible. Mica of good quality satisfies this requirement admirably. However, other insulators can also be used and thin films made of vitreous enamels have proven to be entirely satisfactory. The insulation is made as thin as it can be made conveniently.

FIG. 11.



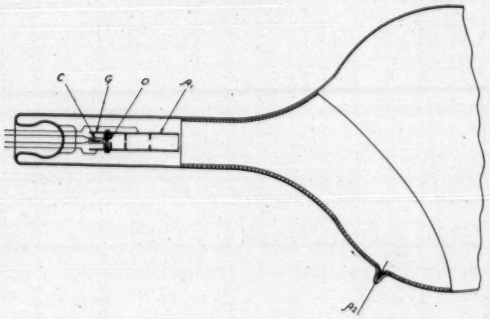
The sensitivity of the mosaic is of the same order as that of corresponding high vacuum cæsium oxide photocells. The same is true also of the color response. The spectral characteristic is shown on Fig. 11. The cut-off in the blue part of the

spectrum is due to the absorption of the glass. The actual color sensitivity of the photo-elements themselves is shown as a dotted curve.

The electron gun producing the beam is quite an important factor in the performance of the iconoscope. Since the resolution is defined by the size of the spot, the gun should be designed to supply exactly the size of spot corresponding to the number of picture elements for which the iconoscope is designed. For the given example of 76,000 picture elements and a mosaic plate about 4″ high, the distance between two successive lines is about .016″ and the diameter of the cathode ray spot approximately half of this size. This imposes quite a serious problem in gun design.

The electron gun used for this purpose is quite similar to the one used for the cathode ray tube for television reception, or the kinescope, which has already been described in several papers.[5] The components of the gun are shown in Fig. 12.

FIG. 12.



It consists of an indirectly heated cathode, C, with the emitting area located at the tip of the cathode sleeve. The cathode is mounted in front of the aperture O of the controlling element, G. The anode A_1 consists of a long cylinder with three apertures aligned on the same axis with cathode and control element. The gun is mounted in the long narrow

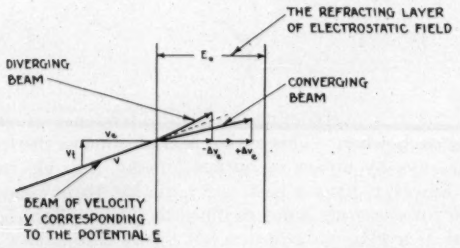
[5] V. K. Zworykin, *Jour. Radio Engineering*, December, 1929.

glass neck attached to the spherical bulb housing the mosaic screen. The inner surface of the neck as well as the part of the sphere is metallized and serves as the second anode for the gun and also as collector for photo-electrons from the mosaic. The first anode usually operates at a fraction of the voltage applied to the second anode, which is approximately 1000 volts.

The focusing is accomplished by an electrostatic field set up by potential differences applied between parts of the electron gun, and between the gun itself and the metallized portion of the neck of the iconoscope.

If an electron enters the field along the lines of force, its velocity, but not the direction of motion, will be affected. If an electron enters the field with velocity, V, at an angle α, as shown on Fig. 13, both the velocity and the direction will be

FIG. 13.



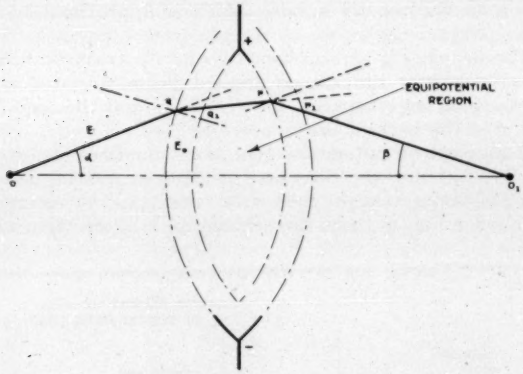
affected, as shown by the vector diagram. In case the field is accelerating, the direction of motion of the electron will be bent toward the axis of symmetry of the field, and if the field is decelerating, the electron will be deflected in the opposite direction. Thus a stream of electrons can be made to converge or diverge.

This interaction between the electrons and electrostatic field can be used to form a sort of lens, as shown on Fig. 14. The lens in this case is converging, but it can be changed to a diverging one simply by reversing the potentials.

The same effect can be accomplished by a field produced by

a difference in potential of two cylindrical electrodes or between two diaphragms. The lines of force in both cases will force the electrons of a beam, moving inside of these electrodes,

FIG. 14.



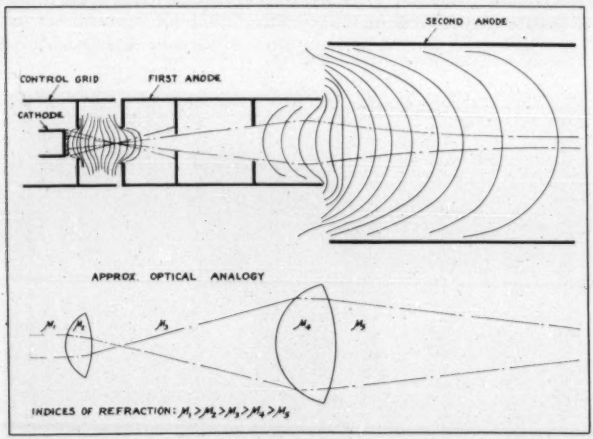
toward the axis, overcoming the natural tendency of electrons to repel each other. This action is analogous to the focusing of light rays by means of optical lenses. The electrostatic lenses, however, have a peculiarity in that their index of refraction for electrons is not confined to the boundary between the optical media, as in optics, but varies throughout all the length of the electrostatic field. By proper arrangement of electrodes and potentials, it is always possible to produce a complex electrostatic lens which will be equivalent to either positive or negative optical lenses.

The distribution of electrostatic fields in the electron gun is shown on Fig. 15. In this particular case, the total action of fields on electrons is approximately equivalent to a combination of two non-symmetrical lenses, as is shown in the same figure.

The first lens forces the electrons through the aperture of the first anode and assure the desired control of the beam by the control element, *G*. The final focusing of the beam on

the mosaic is accomplished by the second lens created by the field between the end of the gun and the neck of the bulb. Thus, the final size of the spot on the mosaic, as in its optical

FIG. 15.



analogue, depends chiefly on the size of the active area of the cathode and the optical distances between the cathode, lenses and the mosaic.

The deflection of the electron beam for scanning the mosaic is accomplished by a magnetic field. The deflection coils are arranged in a yoke which slips over the neck of the iconoscope. The scanning is linear in both vertical and horizontal directions and is caused by saw-tooth shaped electrical impulses passing through the deflecting coils and generated by special tube generators.

From the color response curve shown on Fig. 11, it is clear that the iconoscope can be used not only for transmission of pictures in visible light but also for pictures invisible to the eye, in which the illumination is either by ultra-violet or infra-red light.

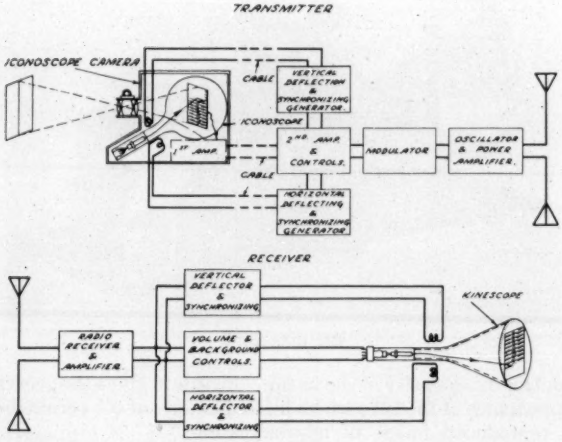
The present sensitivity of the iconoscope is approximately

equal to that of a photographic film operating at the speed of a motion picture camera, with the same optical system. The inherent resolution of the device is higher than required for 76,000 picture element transmission. Some of the actually constructed tubes are good up to 500 lines with a good margin for future improvement.

FIG. 16.

Since the iconoscope is practically a self-contained pickup unit, it is possible to design a very compact camera containing the iconoscope and a pair of amplifier stages connected with the main amplifier and deflecting units by means of a long cable. Since the camera is portable, it can be taken to any point of interest for the transmission of a television picture. The photograph of such a camera is shown on Fig. 16.

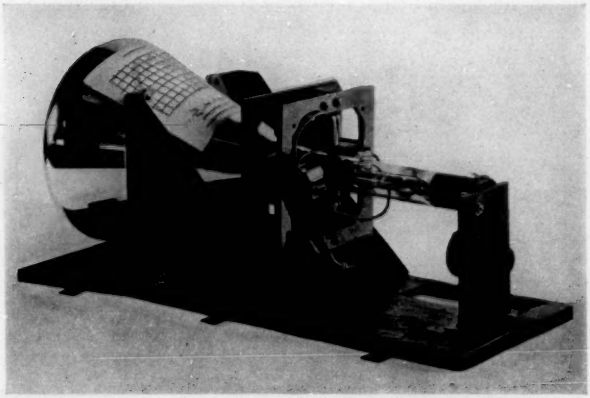
FIG. 17.



The complete block diagram of the circuit associated with the transmitting and receiving ends of the whole system is shown on Fig. 17, where the components and their location in the system are indicated. Naming the units in order, we have for television from the studio: The iconoscope camera, the picture signal and synchronizing signal amplifiers, the control and switching equipment, the modulating and radio transmitter equipment. The units comprising the television receiver are: A radio receiver, the cathode ray unit or kinescope, and its associated horizontal and vertical deflecting equipment.

The name "kinescope" has been applied to the cathode ray tube used in the television receiver to distinguish it from ordinary cathode ray oscilloscopes because it has several important points of difference: for instance, an added element to

FIG. 18.



THE KINESCOPE.

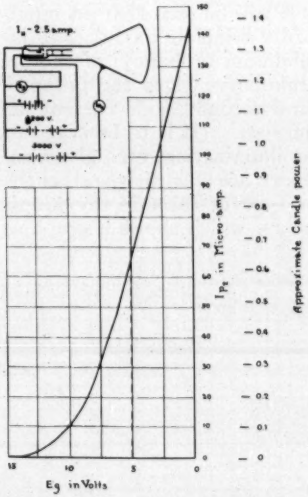
control the intensity of the beam. Figure 18 gives the general appearance of the tube which has a diameter of 9", permitting a reproduced image of approximately $5\frac{1}{2}'' \times 6\frac{1}{2}''$. The electron gun is quite similar to the one used for the iconoscope, except that it operates at a higher potential for the second anode.

As in the latter, the gun is situated in the long, narrow neck attached to the large cone-shaped end of the kinescope, the inner surface of the cone being silvered or otherwise metallized to serve as the second anode. The purpose of the second anode, A_2, is to accelerate the electrons emerging from the electron gun and to form the electrostatic field to focus them into a very small, threadlike beam.

After leaving the first anode, the focused, accelerated beam impinges upon the fluorescent screen deposited upon the flat

end of the conical portion of the kinescope. The fluorescent screen serves as a transducer, absorbing electrical energy and emitting light. Thus there is produced a small bright spot on the screen, approximately equal in area to the cross-section of the beam. The fluorescent screen is very thin, so a large portion of the emitted light is transmitted outside of the tube as useful illumination.

FIG. 19.

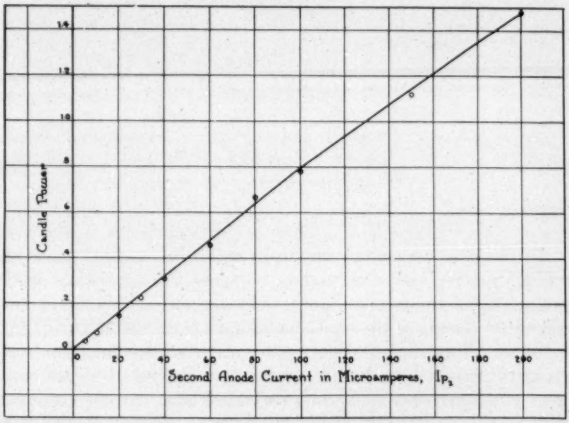


In order to reproduce the light intensity variations of the original picture, it is necessary to vary the intensity of the spot of light upon the fluorescent screen. This is accomplished by means of the control element, G, of the electron gun. For satisfactory reproduction, the control of the electron beam intensity should be a linear function of the input signal voltage. Furthermore, it is very essential that during the exercising of this control the sharp focusing of the spot shall not be destroyed. Still another requirement is that this control will not affect the velocity of the electron beam because the de-

flection of the beam is inversely proportional to its velocity and, therefore, a slight change due to picture modulation would disturb the image, making the bright lines shorter and the darker lines longer. As a result of careful design, the variation of velocity of the beam (from complete cut-off to full brilliancy) in the kinescope is so small as to be unnoticeable to the observer of the picture.

The characteristic curve of the kinescope is shown in Fig. 19. From this it will be seen that an input of 10 volts A.C. will give practically complete modulation (i.e., a change from maximum to minimum brilliancy) of the cathode ray beam. The shape of this curve gives the proportionality between input voltage and second anode current and corresponding brightness of the spot. (It is to be noted that the values of current, voltage, illumination, etc., given on Fig. 19, and all figures in this report, are illustrative rather than specific values for a particular type of cathode ray kinescope tube.) By referring to Fig. 20, which shows a graph of the relation of

FIG. 20.



second anode current to the light emitted from the fluorescent screen, it will be noticed that a linear proportionality exists.

Therefore, we can draw the conclusion that a television picture, varying in shade from black to white, will have accurately reproduced all the intermediate shadings necessary for good half-tone pictures.

The material used for the fluorescent screen is a synthetic zinc ortho-silicate phosphor almost identical with natural Willemite. Zinc ortho-silicate was chosen because of its luminous efficiency, its short time lag, its comparative stability and its resistance to "burning" by the electron beam. The good luminous efficiency is due to the fact that the light, green in color, emitted by the zinc ortho-silicate lies in the visible spectrum in a narrow band peaked at 5230A, close to the wavelength of maximum sensitivity of the eye (5560A), as shown in Fig. 21.

FIG. 21.

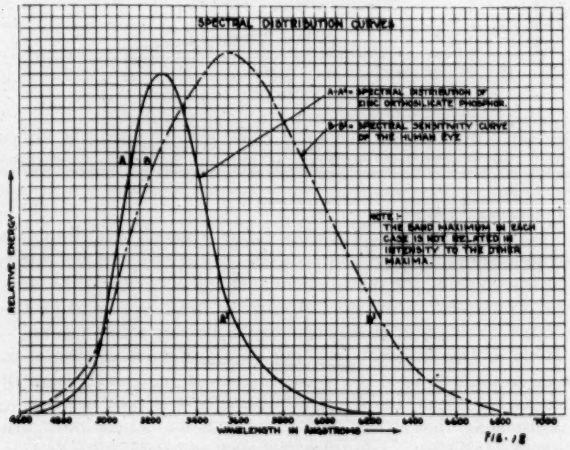
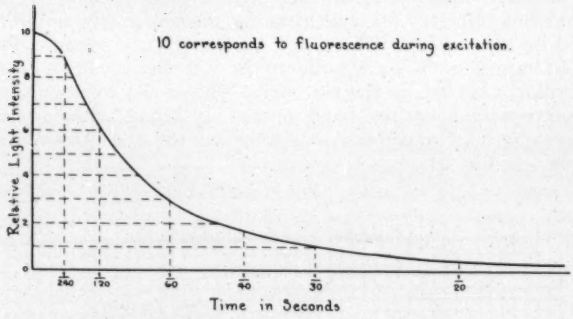

SPECTRAL DISTRIBUTION CURVES
A-A'- SPECTRAL DISTRIBUTION OF ZINC ORTHO-SILICATE PHOSPHOR.
B-B'- SPECTRAL SENSITIVITY CURVE OF THE HUMAN EYE
NOTE:- THE BAND MAXIMUM IN EACH CASE IS NOT RELATED IN INTENSITY TO THE OTHER MAXIMA.
RELATIVE ENERGY
WAVELENGTH IN ÅNGSTROMS
A
B
A'
B'
Fig. 18

Figure 22 shows the time decay curve of the zinc-ortho-silicate luminescence. The decay curve shows that at the end of approximately 0.06 second practically all visible luminescence has ceased. For reproducing 24 pictures per second, the decay curve of the ideal phosphor should be long enough so that the

phosphor just loses its effective brilliancy at the end of 1/24th of a second. If the time of decay is too long, the moving portions of the picture will "trail," as, for instance, the path of a moving baseball would be marked by a comet-like tail. If the time of decay is too short, flicker is noticeable because of

FIG. 22.



the space of comparative total darkness between the times when the fluorescent material is excited between successive pictures.

SCANNING.

The requirement of transmitting the picture impulses through a single channel introduces the necessity of scanning; that is, exploring the picture area, element by element, in some logical order in an interval of time so brief as not to be detectable by the human eye due to its persistence of vision.

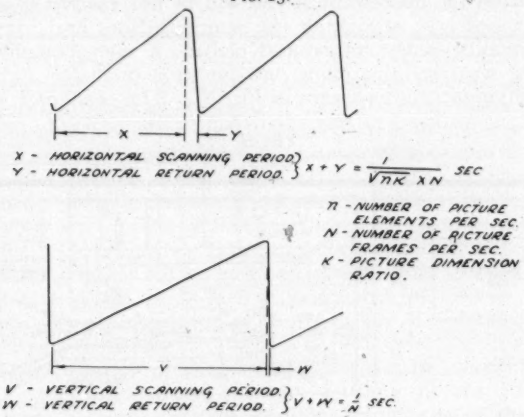
One of the simplest methods of scanning a picture is to cause a spot of light to sweep across it in a succession of parallel horizontal lines. The motion of the spot across the picture may be either uni-directional or sinusoidal. An example of the latter type of scanning is employed with motion picture film in the system described in an earlier paper.[6] An example of uni-directional motion in scanning is that produced by the Nipkow disc widely used in television.

[6] V. K. Zworykin, "Television with Cathode Ray Tube for Receiver," *Radio Eng.*, Vol. IX, No. 12, December, 1929, pp. 38–41.

In the present system the scanning is also uni-directional and is accomplished by deflecting the electron beams, both of the iconoscope and kinescope, by means of electromagnetic fields. The beam traces a succession of equally spaced horizontal lines across the fluorescent screen, reconstructing the television picture in the identical manner that the spot at the transmitter has scanned it, beginning from the top downward and after the last line jumping back to the position at the start of a new picture.

In order to scan with a cathode ray beam in this manner, two variable magnetic fields are applied to the beam just as it emerges from the electron gun; a vertical one, pulsating N times per second, and a horizontal one, pulsating as many times faster as the number of lines in the picture.

FIG. 23.


X
Y
X - HORIZONTAL SCANNING PERIOD.
Y - HORIZONTAL RETURN PERIOD.
X + Y = 1 / √nK × N SEC
n - NUMBER OF PICTURE ELEMENTS PER SEC.
N - NUMBER OF PICTURE FRAMES PER SEC.
K - PICTURE DIMENSION RATIO.
V
W
V - VERTICAL SCANNING PERIOD.
W - VERTICAL RETURN PERIOD.
V + W = 1/N SEC.

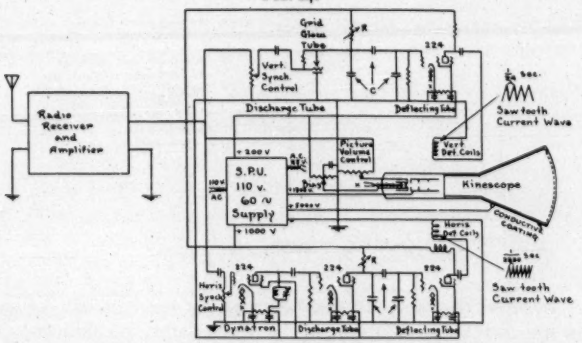
In order that the cathode beam at the receiver will follow the uni-directional scanning at the transmitter, the variation of intensity of both horizontal and vertical deflecting fields plotted against time is of a "saw-tooth" shape as shown in Fig. 23. Each cycle consists of two parts; the first, linear with respect to time and lasting practically the whole cycle, and the

second, or return period, lasting only a small fraction of the cycle. The picture is reproduced during the first part of the scanning period by varying the bias of the control element according to the light intensities of the transmitted picture, as described above.

There are a number of methods that will produce "saw-tooth" shaped electrical impulses. A simple one has been described in an earlier paper,[7] consisting of charging a condenser through a current limiting device such as a saturated two-electrode vacuum valve and then discharging the condenser through a thermionic or gas-discharge tube. The practical limitation of this "saw-tooth" generator lies in the fact that there is no such thing as a completely saturated thermionic tube. Therefore, the condenser cannot be charged exactly linearly with time, and, consequently, the line reproduced on the fluorescent screen will be not exactly straight.

In order to straighten the scanning lines and improve the quality of the reproduced picture, a more complicated circuit was used, involving one dynatron oscillator and two amplifying tubes, as shown in Fig. 24. The condenser, *C*, in

FIG. 24.



the horizontal deflecting circuit is charged continuously through the resistance, *R*. Periodically, at the end of pre-

[7] V. K. Zworykin, "Television with Cathode Ray Tube for Receiver," *Radio Eng.*, Vol. IX, No. 12, December, 1929, pp. 38–41.

determined intervals, the condenser is discharged. During these intervals, the accumulated charge does not reach saturation value, for the time is insufficient. The vacuum tube through which the discharge takes place is controlled by impulses supplied from a dynatron oscillator having a distorted wave shape. The frequency of oscillation of the dynatron (which can be made to vary over a fairly wide range) is initially adjusted approximately to the frequency of the scanning of the transmitter, so that received synchronizing signals will have no difficulty in pulling the dynatron into step with the synchronizing impulses generated at the transmitter. The charging and discharging of condenser, *C*, represent saw-tooth variation of potential, which, when applied to the grid of an amplifying tube, produce saw-tooth current impulses in deflecting coils connected in the plate of the amplifier.

The vertical deflecting circuit is similar to the horizontal circuit just described. Both vertical and horizontal deflecting systems operate on the beam by the magnetic fields generated by coils placed about the neck of the cathode ray tube.

The choice of electro-magnetic deflection in preference to electrostatic was made more as a result of economical consideration than as a mechanical choice. The kinescope for magnetic deflection is much cheaper to make than the one equipped with inside deflecting plates for electrostatic deflection. On the other hand, the electromagnetic deflecting unit itself requires more power and is more costly to build than the electrostatic one. The predominance of one or more factors depends chiefly upon the frequency of deflection and velocity of the beam.

The constants of the electrical circuits for vertical and horizontal deflection are, of course, entirely different, due to the great difference in the operating frequencies of the two deflection circuits.

SYNCHRONIZATION.

When both deflecting circuits are properly adjusted and synchronized with the transmitter, a pattern consisting of a number of parallel lines is seen on the fluorescent screen. The sharpness of the pattern and perfection of its synchronization with the iconoscope determine to a large extent the quality of

the reproduced picture. This pattern is transformed into the picture by applying the picture signal impulses from the transmitter to the control element of the kinescope, so as to momentarily vary the brilliancy of the spot.

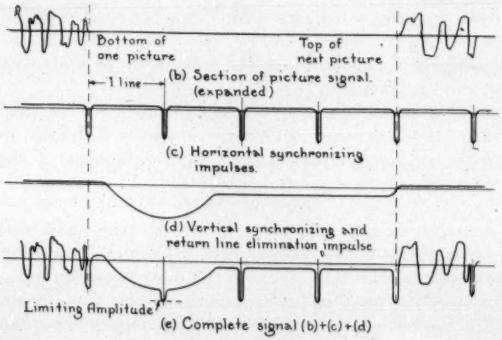
For sending synchronizing signals to the receiver, the impulses produced by the deflecting generators of the iconoscope are fed into the amplifier and united with the picture signals and, therefore, are transmitted over the picture signal channel. They do not interfere with the picture signals, because they occur at an instant when the picture is not being transmitted.

Vertical synchronization is carried out in the same manner, synchronizing impulses for this purpose being transmitted at the completion of each frame.

Considerable advantage is gained from using a synchronizing system in which the beam at the receiver is brought into step with the transmitter at the end of each horizontal line, because momentary disturbances of the nature of static do not appreciably affect the picture.

It will be seen that the radio transmitter is modulated by picture, horizontal synchronizing and vertical synchronizing signals. The resulting composite signal which is fed to the receiver's modulator grid, therefore, appears as shown in Fig. 25, the top curve of which represents the irregular-shaped

FIG. 25.


Bottom of one picture
Top of next picture
1 line
(b) Section of picture signal. (expanded)
(c) Horizontal synchronizing impulses.
(d) Vertical synchronizing and return line elimination impulse
Limiting Amplitude
(e) Complete signal (b)+(c)+(d)

picture signals which are often unsymmetrical about the axis, usually more positive than negative. Both synchronizing signals are arranged to have their peaks on the negative side of the axis. The difference in shape of the horizontal and vertical impulses, of course, is due to the time of duration of both signals and the resultant difference in wave shape is utilized at the receiver for the purpose of separating these two synchronizing impulses. The three signals mentioned above differ in frequency and in amplitude. The peak picture signal amplitude is carefully adjusted to be always less than the horizontal and vertical impulses, the amplitude of the latter being approximately equal.

The separation of the three signals at the receiver is accomplished by a very simple means which is described in detail in another paper,[8] so that the fundamentals only will be mentioned here. If we trace the signals at the receiver from the antenna through the radio receiver and amplifier, shown in Fig. 24, we find that they are applied to three independent units, the vertical deflecting system, the horizontal deflecting system and the input to the kinescope. The synchronizing impulses do not affect the picture on the kinescope because they are transmitted at a time when the cathode ray beam is extinguished, that is, during its return period. The picture signals do not affect the deflecting circuits because amplitude selection is utilized; that is, the amplitude of the picture signals is never sufficient to affect the input tubes of either deflecting system. The selection between vertical and horizontal synchronizing impulses is made on the basis of wave shape selection. A simple filter in each of the input circuits of the two deflecting units gives satisfactory discrimination against undesired synchronizing impulses. The plate circuits of both dynatron input tubes contain circuits approximately resonant to the operating periods of their respective deflecting circuits, thus aiding in the matter of selectivity.

When the electron beam returns to the position from which it starts to trace a new line, and particularly when it returns from the bottom of the picture to start a new frame, an undesirable light trace, called the return line, is visible in the picture. To eliminate this the synchronizing impulses which

[8] R. D. Kell, *Proceedings I. R. E.*, December, 1933.

are in the negative direction are applied to the control electrode of the kinescope, so as to bias it negatively and thus eliminate the return line by extinguishing the beam during its return.

To produce a picture, the intensity of light on a fluorescent screen is varied by impressing the picture signal on the kinescope control element. If the bias adjustment on the kinescope is set so that the picture signals have the maximum swing on the characteristic curve of the kinescope (shown in Fig. 19) a picture with optimum contrast is produced. The picture background, or the average illumination of the picture, can be controlled by the operator by adjusting the kinescope bias.

REPRODUCING EQUIPMENT.

The arrangement of the television receiver built for these tests is shown in Figs. 26 and 27. The former is a photograph of the chassis containing the deflecting unit and kinescope. This chassis slides as a unit into the cabinet. Figure 27 is a photograph of the complete receiver which contains a power unit, kinescope unit, two radio receivers—one for picture and one for sound signals—and a loud speaker.

The reproduced image is viewed in a mirror mounted on the inside lid of the cabinet. In this way the lid shields the picture from overhead illumination. This method also affords a greater and more convenient viewing angle. The brilliancy of the picture is sufficient to permit observation without the necessity of completely darkening the room. Since this type of television receiver has no moving mechanical parts, it is quiet in operation.

The next pictures show the results obtained by means of the above described system. Figures 28 [9] and 29 show photographs of the fluorescent screen of the kinescope when the same pictures as used for Figs. 2 and 3 were being transmitted.

Figures 30 and 31 are actually the pictures transmitted with the iconoscope camera in the studio and outdoors.

With the advent of an instrument of these capabilities, new prospects are opened for high-grade television transmission. In addition, wide possibilities appear in the application of such

[9] Courtesy of Mr. R. D. Kell.

FIG. 26.

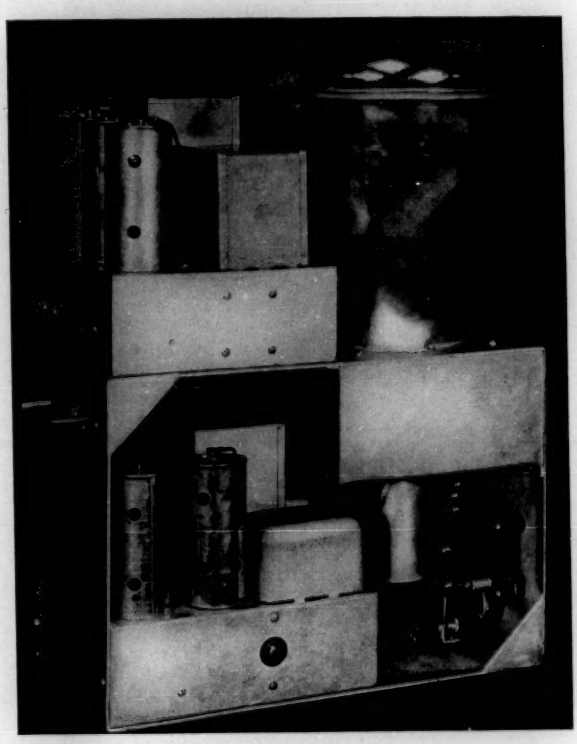


FIG. 27.

FIG. 28.

FIG. 29.

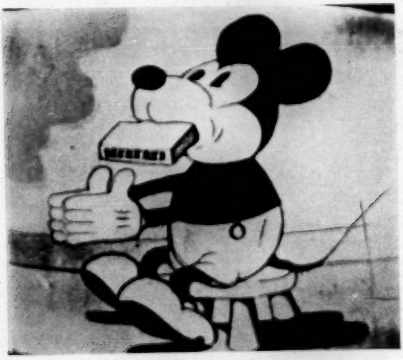


FIG. 30.

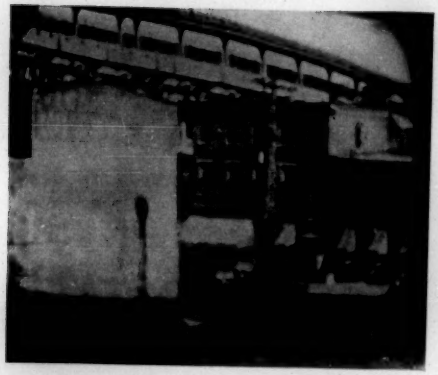
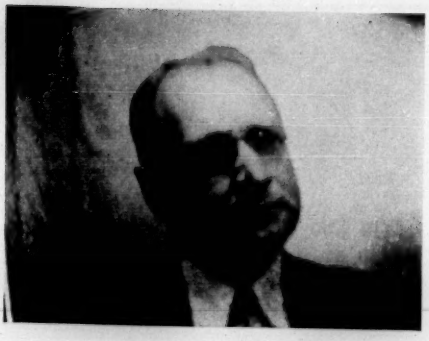


FIG. 31.



tubes in many fields as a substitute for the human eye, or for the observation of phenomena at present completely hidden from the eye, as in the case of the ultra-violet microscope.

The writer wishes gratefully to acknowledge the untiring and conscientious assistance of Messrs. G. N. Ogloblinsky, S. F. Essig, H. A. Iams, A. W. Vance and L. E. Flory, who carried on much of the theoretical and experimental work connected with the development which has been described in the foregoing, and whose ability was the major factor in the successful solution of the many problems arising in the course of this work.

Forty-eight Varieties.—The National Lumber Manufacturers Association started something when it decided to prepare a number of wood sample sets for distribution to schools. Demands for such sets have become so insistent that 1000 additional are now in course of preparation. Each set contains samples of forty-eight species of the most important commercial woods produced in this country. The cost is surprisingly low. Each wood block is $2\frac{1}{4} \times 5 \times \frac{5}{8}''$. It has an attached printed label describing its species, giving its botanical and commercial names, the area in which the tree grows, annual production, commercial uses and importance, peculiar properties and the commercial source of supply.

Naming the 48 species would consume many a long winter evening for most of us. They are:

Softwoods.

Eastern Hemlock	Eastern Spruce	Arkansas Soft Pine
Shortleaf Pine	Western Red Cedar	Sitka Spruce
Sugar Pine	Tidewater Red Cypress	Ponderosa Pine
Engelmann Spruce	Incense Cedar	Eastern Red Cedar
Douglas Fir	Northern White Cedar	Tamarack
Idaho White Pine	Western Larch	Part Oxford Cedar
Longleaf Pine	West Coast Hemlock	Northern White Pine
White Fir		Redwood

Hardwoods.

Appalachian White Oak	Basswood	Southern White Oak
Red Gum	Hard Maple	Hickory
Magnolia	Birch	Appalachian Red Oak
Rock Elm	Soft Elm	Norway Pine
Yellow Poplar	Chestnut	Sycamore
Beech	Cottonwood	White Ash
Southern Red Oak	Black Walnut	Sap Gum
Soft Maple	Cherry	Tupelo
	Willow	

C.

THE IONIZATION BY COSMIC-RAY PARTICLES AND SWIFT BETA-PARTICLES.*

BY

GORDON L. LOCHER, Ph.D.,

National Research Fellow.

BARTOL RESEARCH FOUNDATION

Communication No. 83.

Whatever the nature of the primary cosmic-ray entities may prove to be, we are at present only able to detect them by means of the ionization effects of associated corpuscles, whether by measuring the rate of production of ions in ionization chambers and electroscopes, or by counting the number of particles or groups of particles with Geiger-Müller counters, or by photographing their tracks in cloud expansion chambers. Each of these methods has certain advantages peculiar to itself, and combinations of them have recently been found convenient means of deducing other data. For example, we may find the rate at which penetrating corpuscles pass through a given region, with counting tubes, and measure the corresponding rate of ionization in a similar region with an electroscope. These data should suffice for determining the average ionization per centimeter path of the particles, within the same limits of certainty that we can depend on the counters to record every track passing through them, and on the electroscope to account for every ion-pair liberated in it. By an experiment of this kind, Kolhörster and Tuwim [1] calculated that about 135 ion-pairs were formed per centimeter of cosmic-ray particle track. But if we examine the condensation along identified cosmic-ray cloud tracks, we find somewhat less than one-third of this ionization, so that cosmic-ray tracks usually closely resemble those of the fastest β-particles

* This paper was read, in part, at the Cosmic-Ray Symposium, A. A. A. S. meeting, Atlantic City, N. J., December 1932. Some revisions and additions have since been made, especially in the latter part.

[1] Kolhörster and Tuwim, *Zeit. für. Phys.*, 73, 130 (1931).

of radioactive origin.[2] The discrepancy seems capable of explanation on two bases. The first indicates that the method of Kolhörster and Tuwim is at fault, and the second, with which I shall principally concern myself, shows how the counting of droplets in cloud tracks may lead to erroneous values of the specific ionization, because of a newly-discovered process of dissipation of energy along individual tracks passing through matter.

In connection with the first of these considerations, let us consider the plurality of fast corpuscles constituting, or attending, the arrival of the cosmic-ray agent. The examination of about 350 cosmic-ray tracks, photographed by three observers at different places[3,2,4], has shown that about 50 tracks, or one in seven, is grouped with one or more companion tracks. The tracks of each group usually converge to a point in some relatively massive material near the cloud chamber. The discovery of these groups of fast secondaries invalidates the measurements of ionization per centimeter of path, as determined by a combination of ionization chambers and counters, unless some way of determining the number of individual rays passing through the chamber is devised. The counters record the passage of a simultaneous group of rays as a *single* event, while the ionization chamber records the total ionization produced. Kolhörster and Tuwim sustain their value for the specific ionization, by saying that it includes the average ionization of the *secondaries*, in addition to that of the primaries. This could at best only approximate the truth, since the number of secondaries entering any region depends on the material through which the primaries have lately traveled, and on the penetrating power of the secondaries. The "Übergangseffekte" found by Hoffmann,[5] Stienke,[6] and others,[7] clearly illustrates this point. To make the determination by their method valid, Kolhörster and Tuwim would

[2] Locher, *Phys. Rev.*, **39**, 883 (1932).

[3] Skobelzyn, *Zeit. für. Phys.*, **54**, 686 (1929); *Comptes Rendus*, **189**, 55 (1929).

[4] Anderson, *Phys. Rev.*, **41**, 405 (1932).

[5] Hoffmann and Pforte, *Phys. Zeit.*, **31**, 347 (1930).

[6] Steinke, *Phys. Zeits.*, **31**, 1019 (1930).

[7] Schindler, *Zeit. für Phys.*, **72**, 625 (1932); Steinke and Schindler, *Zeit. für Phys.*, **75**, 115 (1932).

accordingly have had to use an ionization chamber and counter of the same material and wall-thickness. I shall apply the term "specific ionization" to the ionization per centimeter path of *individual* tracks.

We may make an estimate of the specific ionization along cloud tracks by counting the number of droplets, each of which is supposed to indicate an ion, or ion-pair. But now it appears that such estimates are very unreliable, because of the rather frequent production of dense ion-clusters whose drops are too close together for resolution, except electrical resolution, and whose ionization represents a considerable fraction of the ionization along the path. Along all cloud tracks of β-particles that I have ever seen, these clusters appear.

I shall presently offer reasons for believing that large numbers of these clusters are the result of the generation and immediate photoelectric absorption of soft x–radiation in the gas, following the passage of the particle through it. In other words, they seem to arise from a multiple-ionization process similar to the effect discovered by Pierre Auger, in 1925, in connection with the starting-points of x-ray photoelectrons in gases. (This is generally known as auto-ionization, or the Wilson-Auger effect[13,8]).

The generally-accepted picture of the process of ionization of a gas by a fast corpuscle is that the field of the passing corpuscle exerts sufficient force on certain of the electrons near which it passes to drive them from the atoms, usually with almost zero velocity, but that, occasionally more or less "direct hits," or very close approaches occur, which result in the appearance of branches on the tracks, often with appreciable deflection of the primary particle. The collision branches start off nearly at right angles to the generating track, if the latter is slow, but make smaller angles if its velocity is near that of light. It has been shown by Champion[9] that in cases where the primary β-particle of less than 10^6 volts energy divided its energy equally with an electron previously at rest, the angles between the tracks agreed with

[8] Auger, *Comptes Rendus*, **180**, 65 (1925); *Jour. de Phys. et Rad.*, **6**, 205 (1925); *Ann. de Phys.*, **6**, 183 (1926).

[9] Champion, *Proc. Roy. Soc.*, **A136**, 630 (1932).

those calculated on relativistic mechanics, with the exception of a single instance in which the three branches were not coplanar. Yet aside from this case, difficulties have been recognized in connection with various aspects of the deflection and scattering of β-particles, and it has been suggested that certain of these discrepancies might be explained as due to the emission of radiation, resulting from acceleration of the particle at collision, or the production of excited states in the atoms participating in the collisions.

Secondaries of high energy, produced by collisions of cosmic-ray particles, should mostly proceed in the direction of the primary particle, if they are generated in accordance with principles extended from radioactivity theory. Yet the evidence from experiments with cloud chambers and counters is that the deviations of these secondaries are often very large. Most surprising of all is the recent observation by Skobelzyn[10] of *upward-directed* convergent groups of cosmic-ray tracks, an observation hardly in accord with the literal concept that *downward-directed* cosmic-ray primaries produce secondaries by "elastic" collision. Some months ago I observed at least two pairs of high-energy tracks that diverged upward from below the chamber, but they were attributed to accidental simultaneity of arrival of independent particles from different directions. I am still at a loss to explain these tracks, if they come from the action of a downward-directed primary entity. unless we assume that in the nuclear disruptions that give rise to the groups, it is totally inadequate to consider the momenta of the incident and emergent entities. There seems to be a finite probability that the secondaries will be ejected in *any* direction. If the energies of these secondaries were as low as those corresponding to radioactive transitions, the upward-directed groups could be explained by assuming the involvement of nuclear *excitation*, followed by transitions that ejected electrons in random directions; but I do not know of any nuclear transitions of 10^8 e-volts, or more, of energy.[11]

I believe that while some of the groups of cosmic-ray

[10] Skobelzyn, *Comptes Rendus*, **195**, 315 (1932).

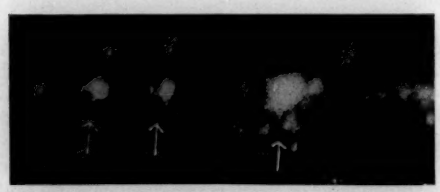
[11] Cloud photographs of Stösse have since shown that cosmic-ray disintegrations may proceed from *several* foci, from which tracks may diverge upward as well as downward. (Locher, *Phys. Rev.*, **44**, Nov. 1, 1933.)

tracks originate from collision processes, some derive their energy from the disrupted nucleus. On this view, the cosmic-ray entity supplies the energy to start the nuclear explosion, which then proceeds under its own power, A great deal more experimental work on the micro-effects of cosmic-ray absorption will have to be done before we can decide just what processes are involved in these disintegrations.

Leaving the unanswered questions in regard to the ejection of nuclear corpuscles by cosmic-rays, let us turn to the more mundane phenomena of the fine structure of the ionization of cosmic-ray particles and fast β-particles, as they affect the values of the specific ionization determined from direct ion counts along cloud tracks.

This ionization may be divided into two kinds: primary ionization, consisting of the ions liberated with energy below the lowest critical ionization energy of the gas molecules, and secondary ionization, consisting of ions produced by primary ones that are ejected with sufficient energy to produce subsidiary ionization by collision. It has been recognized that this latter class accounts for one-half to three-fourths of the total ionization along tracks of high-speed β-particles, and I shall present qualitative evidence for believing that it accounts for the dissipation of more of the energy than was previously known. The vast majority of the primary ions that produce secondary ionization are of low energy; their paths appear as short, dense clusters, like irregular beads on the thin string of primary ionization (Figs. 1, 2, and 3). It seems to have been tacitly assumed that the clusters result from relatively close collisions of the primary particle with an electron, i.e. that they

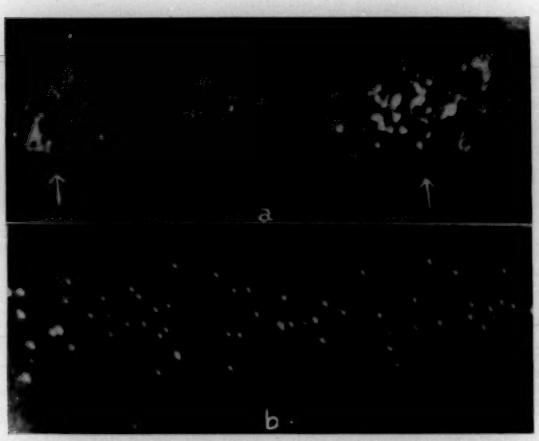
FIG. 1.



Segment of a fast β-ray track, showing short branches of two sizes (air at 58 cm. pressure. Mag. $\times$ 5.8.)

are "collision-branches." In this connection, C. T. R. Wilson[12] made a careful analysis of the energies and directions of short branches, above certain energy limits, as related to the velocity and deflection of the generating particle. He found

FIG. 2.



Segments of two diffuse cosmic-ray tracks. (*a*) shows two clusters; (*b*) is free from clusters (specific ionization 27 cm.$^{-1}$). (Argon at 64 cm. pressure. Mag. × 5.8.)

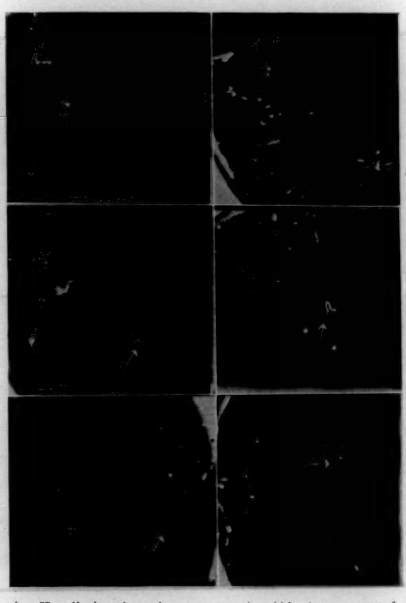
that part of the branches had energies and momenta that were in agreement with the observed deflections of the generating particle, but that there were cases of branches of considerable range, accompanied by only small deflections of the primary ray; he suggested that soft radiation generated along the path might be involved in these anomalous deflections. Unfortunately, the shortness of the tracks, and the correspondingly small deviations of the generating particle, make it impossible to apply this important kind of analysis to very low-energy branches, where I believe the anomaly plays a more conspicuous part.

If we examine the short branches appearing along cloud tracks in atmospheres of various constitutions, we find several

[12] C. T. R. Wilson, *Proc. Roy. Soc.*, **A104**, 192 (1923).

features of interest: first, that the number of denser clusters of the ions increases with the atomic number of the gas; second, that for any particular atmosphere, many of the clusters fall into groups the members of each of which are of very similar energy; and third, that the energies spent in

FIG. 3.



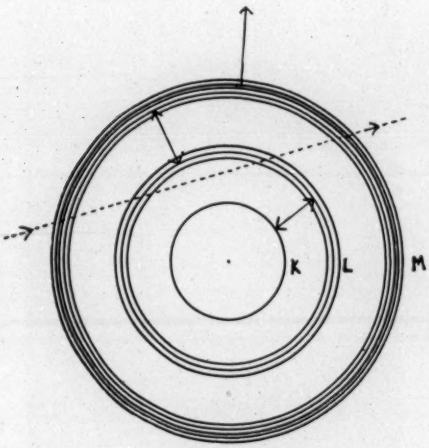
β-ray tracks showing K-radiations branches (at arrows). (Air + 1 per cent. krypton, at 58 cm. pressure. Mag. × 0.23.)

forming these characteristic clusters correspond, at least approximately, to characteristic energy transitions of the atoms of the atmosphere.[14] From this evidence, it is concluded that

[14] For a cloud atmosphere of hydrogen, the writer has found that branches whose energies are as low as 500 volts (oxygen K-branches) are recognizable. C. T. R. Wilson gives 1500 volts as the corresponding minimum for air.

the clusters are ejected by the action of *characteristic radiation generated in the gas by the passage of the particle through it.* The secondary ionization along tracks falls, then, into two categories: "collision-branches," possessing a wide range of energies, and "radiation-branches," possessing few groups of energies, characteristic of electron transitions of the atoms of the gas. It is exceedingly dfficult to tell how the energy

FIG. 4.

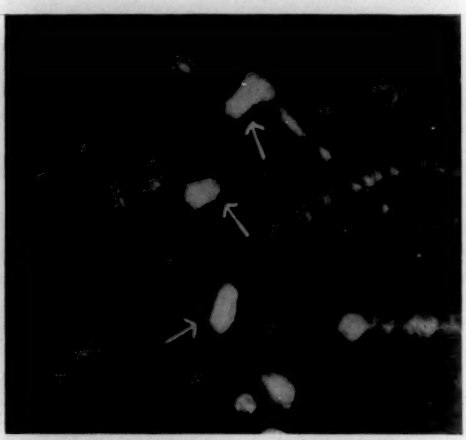


dissipated by these two processes is distributed between them, since the branches are mostly very small. If the ejection of electrons by radiation applies also to the peripheral electrons, as it probably does, the energies involved are entirely too small to make tracks of appreciable length. It is accordingly impossible to tell by examining cloud tracks how much of the *primary* ionization is accomplished by means of the characteristic radiation originating from transitions of the optical electrons, and how much by collision processes that do not involve the generation of radiation. In this connection, C. T. R. Wilson[12] has found that the primary ionization agrees with

Thomson's theory, if the minimum energy that a β-particle must have to ionize is about 7 volts, in air, which corresponds to the *resonance* potential of nitrogen, not any ionization potential.

Radiation-branches will be called "K–branches," "L-branches," etc., accordingly as they arise from K, L, etc., radiations. The manner of their production is exactly similar

FIG. 5.



Auger-branches at the starting-points of x-ray photoelectrons in argon + hydrogen; Energy of branches: 2930 volts. (95 per cent. hydrogen + 5 per cent. argon, at 58 cm. Mag. × 5.8.)

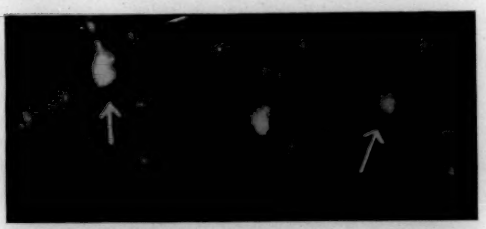
to that of the branches that occur at the starting-points of x-ray photoelectrons in gases, as observed by C. T. R. Wilson[13] and by Auger,[8] which were identified by the latter as due to the generation and photoelectric absorption of characteristic x-radiation in the parent-atom (Figs. 5 and 6).

The mechanism by which radiation-branches are generated along β-tracks will be described with the aid of the energy-level diagram, Fig. 4. The path of the β-particle, which passes near or through the atom, is indicated by the dotted line.

[13] C. T. R. Wilson, *Proc. Roy. Soc.*, **A104**, 1 (1923).

Suppose, for example, that a K → L transition is produced by the field of the passing particle. This will be followed by an L → K transition, with the emission of a K-quantum. If this

FIG. 6.

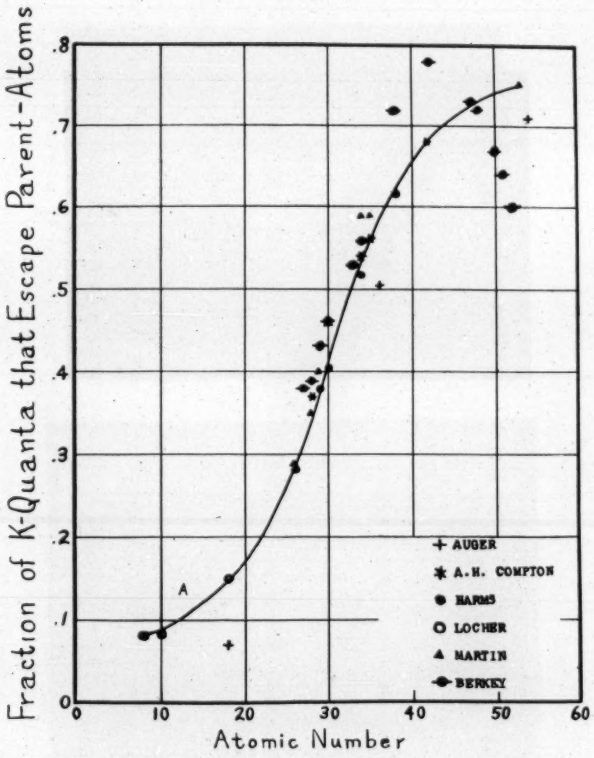


Auger-branches in neon + hydrogen, similar to those of Fig. 5; energy: 840 volts. (95 per cent. hydrogen + 5 per cent. neon, at 58 cm. Mag. × 5.8.)

K-quantum is absorbed by a peripheral electron, a K-branch appears on the β-track. Similarly, if an L → M excitation is produced, followed by an M → L transition, an L-quantum is liberated which may give rise to an L-branch on the track. By analogous processes, (K–L)-branches, (L–M)-branches, etc., may be produced, involving transitions between all energy levels from the K, to the optical ones. That the branches arise from the *same atom* in which the radiation is generated seems very certain, with rare exceptions, since the absorption coefficient of the parent-atom for its own radiation has been shown to be enormously greater than that of any other atom. This is shown by Fig. 7, which represents the collected data on the efficiency of the Auger effect for K-radiation; these are believed to be the most reliable data now available.[15] The internal photoelectric conversion of K-radiation is especially high for light elements, being more than 90 per cent efficient for air, and about 85 per cent efficient for argon. Very little is known about the efficiencies of conversion of L and M radiations of any atoms, but rough experi-

[15] Locher, *Phys. Rev.*, 40, 484 (1932).

FIG. 7.



ments indicate that the probability of L-conversion, at least, is also high.[16]

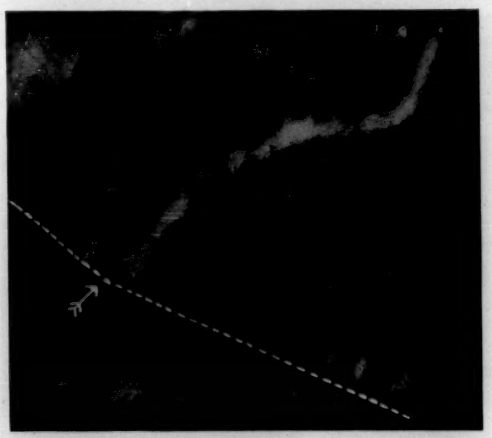
[16] When a K-electron is ejected with V volts of residual energy, by a collision process, $(V + W_k)$ volts of energy are taken from the β-particle, where W_k is the work-function; but if K-radiation ejects an electron with the same energy, only $(V + W_s)$ volts are used, where W_s is the work-function for a more remote electron.

FIG. 8.

FIG. 9.

FIG. 10.

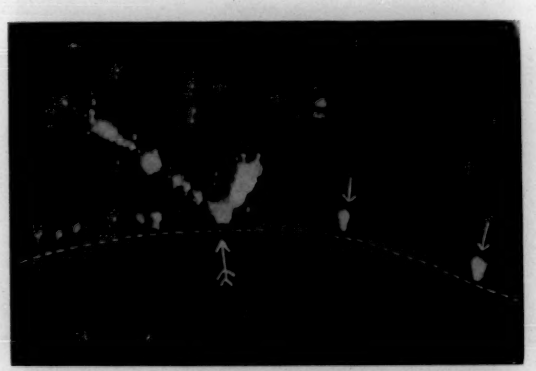
FIG. 11.



Probable radiation-branches on β-ray tracks in air + krypton. The paths of the β-rays are shown by the dotted lines. (Air + 1 per cent. krypton at 58 cm. Mag. × 5.8.)

Interesting examples of K-branches on fast β-tracks are shown in Figs. 3, 8, 9, 10, and 11, made in an atmosphere of air into which was introduced about one per cent of krypton and a trace of xenon. In Figs. 8 and 11, the K-branch is apparently accompanied by an L-branch (short cluster at the starting point). In an atmosphere of argon (containing traces of other noble gases), the K-branches (Fig. 5) are shrunk to short lengths (Fig. 12). From the track in Fig. 12, there emerges a double branch, presumedly a K- and an L-branch originating in a xenon atom. The probability that two branches of this sort should originate from the same point by *collision* processes is infinitesmal. Fig. 13 shows an unusual case, in which a krypton K-branch (and perhaps an L-branch) are produced at the *end* of a track. These branches at the ends of tracks have frequently been noticed before; the evidence is yet too small for one to decide whether the phenomenon indicates an energy-resonance favoring the formation of a characteristic branch, when the energy of the generating particle is equal to the energy of the branch. Fig. 14 shows a branch of energy similar to K-branches of krypton, emerging from a diffuse x-ray track, near the end of its range.

FIG. 12.

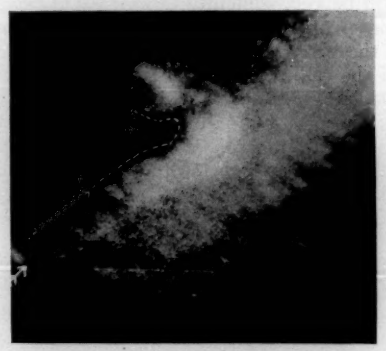


β-ray track in argon, with two small branches (argon-K, see Fig. 5), indicated by small arrows, and a double branch (large arrow), attributed to internal conversion of Xe–K and Xe–L quanta in the parent-atom. (Argon + traces of other noble gases, at 64 cm. Mag. × 5.8.)

FIG. 13.

Branch of about 15,00 volts energy, at end of a β-ray track; believed to be a krypton K-branch.
(Air + 1 per cent. krypton at 58 cm. Mag. × 5.8.)

FIG. 14.



Branch emerging from an x-ray track, near end of its range (Kr K-branch?).
(Air at 58 cm. Mag. × 5.8.)

Although experiments for establishing the *existence* of the radiation-ionization process along β-tracks are most easily interpreted for K-radiation, it is not implied that K-radiation and K-ionization are the major manifestations of the process. The longer tracks arising from excitation of deep energy levels make their identification relatively easy, but the greater abundance of electrons in outer orbits leads one to expect that most of the ionization consists in the dislodgment of peripheral electrons. Branches of low energy due to collision-ionization and to radiation-ionization are not only experimentally indistinguishable, but the mechanisms themselves are very much alike. However, a significant difference between them lies in the fact that during radiation-ionization, the radiation always has a finite chance of escaping from the atom, and, indeed, of escaping detection entirely. Consequently, if a large fraction of the peripheral electrons that are ejected, involve radiation in the process, a considerable amount of the energy drawn from the β-particle is not detected at all.[17] The discrepancies between the energy lost along tracks and the ionization produced, as pointed out by Wilson, substantiate this view, although quantitative determinations of the energy lost by radiation will be very difficult.

Other noteworthy implications of the radiation-branch process are these:

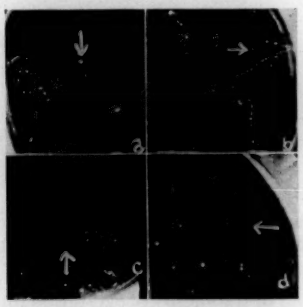
First: If the radiation *escapes* from the track, a bend will occur, corresponding to the momentum lost; from these bends, no branches emerge. Numerous bends without branches were observed to appear on tracks in air, when a small amount of krypton was added to the atmosphere (Figs. 15, 16, and 17). These are believed to arise chiefly from the generation and escape of Kr K-quanta (15,000 volts); the angle of deflection may be large when the momentum of the radiation is comparable with the momentum of the β-particle. Unfortunately, it is usually impossible to distinguish these bends from nuclear deflections. In the case of the diffuse track shown in Fig. 17, however, the specific ionization increased by 60 per cent, after the bend, indicating a considerable diminution in velocity,

[17] This suggests that the inner surfaces of ionization chambers for β-rays and cosmic-rays should be coated with photoelectrically-active material, in order to recover as much as possible of the energy otherwise lost as light and soft x-rays.

which would not be expected if the bend were an ordinary nuclear deflection.

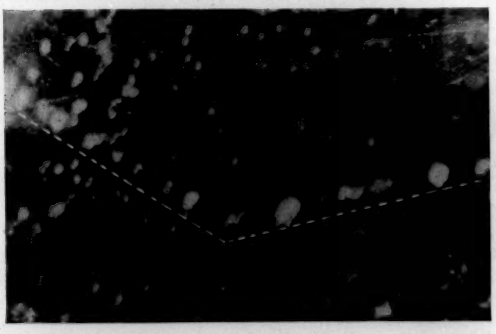
Second: When radiation is involved in the ionization process, momentum need not be conserved in a manner that is evident from the energies and deflections of the tracks, since the energy may spend short interval of time as potential

FIG. 15.



Four fast β-ray tracks showing sharp bends made under the same conditions as those of Fig. 3. The bends in *b*, *c*, and *d* may indicate the escape of krypton K-radiation. (Air + 1 per cent. krypton, at 58 cm. Mag. × 0.23.)

FIG. 16.



Magnified view of bent β-ray track of type shown in Fig. 15. (Mag. × 5.8.)

FIG. 17.

Diffuse β-ray track with sharp bend. The increase of ionization after the bend indicates loss of considerable energy, presumedly by radiation. (Air + 1 per cent. krypton, at 58 cm. Mag. × 5.8.)

energy in an excited atom. In such cases, momentum equal to the momentum of the energy of excitation must be imparted to the atom as a whole. This is added to the thermal agitation of the gas.

Third: The wide departure of the ionization along fast β-tracks and cosmic-ray tracks from a random distribution affects the calculation of the efficiencies of Geiger-Müller counters, for detecting such tracks, as calculated on the basis of the mean specific ionization. In order to compute the probability that no ion-pair will be produced in the sensitive volume, one must know the mean number of (ion-pairs + cluster) per centimeter, i.e., the mean specific *primary* ionization along the tracks.

Fourth: Saturation phenomena in high-pressure ionization chambers and electroscopes are further complicated by radiation-ionization. This deserves especial treatment.

We will now consider qualitatively the effect of radiation-ionization on recombination phenomena in high-pressure ionization chambers. Harper[18] has pointed out that re-

[18] Harper, *Proc. Camb. Phil. Soc.*, **29**, 149 (1933).

combination is of three types (that are not necessarily distinct from one another), namely: *preferential recombination*, the recombination of the electron with its parent positive ion, *initial recombination*, which occurs between ions that are still in the columns that constituted the tracks of the generating particles, and *ordinary recombination*, which occurs after the distribution of the ions has become more or less random. Recalling the discussion in foregoing parts of this paper, the ionization along tracks is also divided into three kinds: *primary ionization*, found along branch-free parts of the tracks, including less than half the total ionization, *collision-secondary ionization*, and *radiation-secondary ionization*, which together account for one-half to three-fourths of the total. The ionization produced at the walls of the vessel and in the gas by the soft characteristic radiation forms a fourth class, of unknown importance. The collision-secondary ionization is produced along branches whose lengths should vary continuously from nothing to the entire unused range of the generating particle, with a distribution that should be easily calculable. The radiation-secondary ionization is produced along branches *whose lengths have a definite series of magnitudes* for each kind of atom in the gas; the relative numbers of tracks of each length may reasonably be assumed to be constant, for generating particles of a given energy (but they are also unknown); the maximum length of the radiation-branches is fixed by the greatest (extra-nuclear) energy transition of the atom from which it originates.

Now it is very evident that preferential, initial, and ordinary recombination will take place to different extents for ions formed by each of the three different processes, so that the saturation phenomena may be divided roughly into three categories: those for primary-, collision-secondary-, and radiation-secondary paths. Moreover, just as recombinations of the three kinds are not sharply distinguishable from one another, neither are the three kinds of ionization to which they apply. For example, if the velocity of the generating β-particles are increased from nothing to a very high value, the primary ionization-density diminishes from a value comparable to that of the secondary branches to so small a value that initial recombination is small, whereas recombination

phenomena along each particular class of *radiation-secondary* branches are the same for any velocity of the generating particle, although the *number* of branches in each class is doubtless a function of its velocity. In order to understand the fine-structure of saturation phenomena at any pressure, we would have to ascertain the ratios of the amounts of energy dissipated by primary, collision-secondary, and radiation-secondary ionization, the distributions of energy among the collision-secondary, and among the radiation-secondary branches, and, above all, the manner in which these ratios and distributions vary with the velocity of the generating β-ray track. With this information at hand, one *might* be able to calculate the losses due to recombination of the three types, for a given distribution of velocities of β-particles. If the pressure in the ionization chamber is altered, so also are the recombination processes for each type of ionization and the mean free paths of the soft characteristic radiation liberated in the gas.

The enormous complexity of the problem is evident. Even if only one variable is altered, for example the penetrating-power of the cosmic-ray particles, the relation between the energy liberated in the ionization chamber and the measured ionization current is altered in an unknown manner and this for a *single gas* at a *single pressure*. For some time to come, we shall likely have to rely on empirical information of rather bad accuracy for interpreting ionization-chamber measurements of the intensities of cosmic-ray particles and β-particles.

The writer is indebted to Dr. W. F. G. Swann for discussion of the phenomena described in this paper.

THE REPRESENTATION OF RADIATION REACTION IN WAVE MECHANICS.

BY

W. F. G. SWANN.

ABSTRACT.

BARTOL RESEARCH FOUNDATION

Communication No. 84.

It is well known that the wave mechanical ψ equation leads to the conclusion that the centroid of the wave mechanical electron should move according to the classical electrodynamic equation of motion in which, however, the terms representing what is commonly called radiation reaction are absent. If $\mathbf{v}$ is the velocity of the electron, the classical rate of change of momentum is $md/dt\{\mathbf{v}/(1 - v^2/c^2)^{1/2}\}$. The equation of motion including radiation reaction terms may be regarded as obtainable by replacing this quantity by one obtained by operating upon it with the operator P^{-1}

$$P = \{1 - \alpha_1 kd/dt + \alpha_2 kd/dt(kd/dt) - \cdots\}^{-1},$$

where α_1, α_2, etc., are constants and $k = (1 - v^2/c^2)^{-1/2}$. The main purpose of the paper is to show that if there be any relativistically invariant ψ equation which leads to the classical equation of motion without radiation reaction terms, then by replacing the vector and scalar potentials $\mathbf{U}$ and φ in that equation by $P(\mathbf{U})$ and $P(\varphi)$, a relativistically invariant equation of motion will be obtained including the radiation reaction terms, provided that the d/dt in P be now regarded as $\partial/\partial t + (\mathbf{u}\cdot\text{grad})$, where $\mathbf{u}$ is the velocity of the wave mechanical density distribution at a point. The purpose is to use the power to produce the equation of motion as a criterion for suggesting the proper modification of the ψ equation to apply in those cases where, on the classical theory, the electron would suffer great acceleration, as in ionization by rapidly moving corpuscles.

The status in wave mechanical theory of what in classical theory is usually termed radiation reaction on an electron is of particular importance in theoretical investigations of the ionization produced by charged particles travelling with velocities very nearly equal to that of light. This particular problem was attacked by the present writer from the standpoint of the classical electrodynamics in 1922,[1] and it was

[1] W. F. G. Swann, "Ionization by Charged Corpuscles with Velocities Approaching that of Light," presented at the Cambridge Meeting of the American Physical Society, December 27–29, 1922. See also more complete paper, W. F. G. Swann, "The Absence of Ionization by Electrons with Speeds Comparable with that of Light," *Phil. Mag.*, S-6, **47**, 306–319, 1924.

shown on that basis that there were grounds for supposing that cessation of ionization should occur for energies of the ionizing particle comparable with 10^9 volts.

In 1932, the writer made a modification of the basic wave mechanical equation for an electron designed to provide for radiation reaction in the electron's equation of motion; and, at his request, Dr. A. Bramley applied the equation to the problem of atomic ionization. The result was to predict consequences qualitatively similar to those predicted by classical electrodynamics, but with the ionization falling to inappreciable amount for energies of the ionizing corpuscle comparable with 10^{10} volts.[2] It must be remarked, however, that the numerical calculation is based upon the assumption of the same magnitude for the radiation reaction term in the electron's macroscopic equation of motion as is given by the classical theory.[3]

The purpose of the present paper is to outline the basis of derivation of the former ψ equation, which has so far only been published in abstract, and to give a more general treatment of the problem.

Outline of Previous Method.—The previous derivation pursues the following lines. The classical equation of motion of an electron is, to a first approximation neglecting relativity,

$$\frac{m}{e}\left(\mathbf{s} - \frac{a}{c}\dddot{\mathbf{s}} + \cdots\right) = \mathbf{E} + [\dot{\mathbf{s}}\mathbf{H}]/c, \qquad (1)$$

where $\mathbf{s}$ is the distance of the electron from the origin, m is the electronic mass, a the classical electronic radius, $\mathbf{E}$ and $\mathbf{H}$ the electric and magnetic fields, and c the velocity of light.

For such a case as that of ionization, where the velocity of the ejected electron is small, although its acceleration may be large, (1) becomes

$$\frac{m}{e}\left(1 - \frac{ad}{cdt} + \cdots\right)\ddot{\mathbf{s}} = \mathbf{E}$$

or

$$\frac{m}{e}\ddot{\mathbf{s}} = \left(1 - \frac{ad}{cdt} + \cdots\right)^{-1}\mathbf{E}. \qquad (2)$$

[2] W. F. G. Swann and A. Bramley, *Phys. Rev.*, S-2, **41**, 393, 1932.

[3] By the macroscopic equation we here refer to the equation of motion of the centroid of the $\psi\psi^*$ distribution as given by wave mechanics.

We may thus regard the problem as one of an electron, without radiation reaction subjected to a field

$$\{1 - (a/c)(d/dt) + \cdots\}^{-1}\mathbf{E}.$$

Again, for small electron velocities [4] and rapid time rates of change of field as in the case of ionization by a β particle with velocity nearly equal to that of light, d/dt, which represents differentiation following the electron in its motion may be replaced by $\partial/\partial t$. For such cases, therefore, it is reasonable that the ψ equation including radiation reaction may be obtained from the ψ equation without such reaction by replacing $\mathbf{E}$ in that equation by $\{1 - (a/c)(d/dt) + \cdots\}^{-1}\mathbf{E}$.

In cases where the operator may be expanded, the apparent perturbation field takes the form

$$\mathbf{F} = \mathbf{E} + (a/c)\partial\mathbf{E}/\partial t + \cdots. \tag{3}$$

For the case where the field $\mathbf{E}$ is produced by a β particle moving with a velocity very nearly equal to c, the field of the β particle remains sensibly constant when referred to the β particle as origin. Thus $\partial\mathbf{E}/\partial t = -c\partial\mathbf{E}/\partial\zeta$ where the velocity of the β particle has been put equal to c as an approximation and $\partial/\partial\zeta$ refers to differentiation parallel to the path of flight of the β particle. For this case, therefore,

$$\mathbf{F} = \mathbf{E} - a\partial\mathbf{E}/\partial\zeta. \tag{4}$$

It may be well at this stage to answer a criticism made by E. J. Williams of the note by A. Bramley and the writer [5] concerning the effect of radiation reaction upon the ionization produced by a high energy β particle. Writing in the *Proceedings of the Royal Society of London*, **139**, pp. 163–186, 1932, he remarks: "In a recent letter to the *Physical Review*, W. F. G. Swann, in a discussion of the nature of penetrating

[4] It is not assumed that the velocity of the *ionizing agency*, a β particle, for example, is small. In general it is nearly equal to the velocity of light.

[5] The paper referred to by Williams is "Electrons as Cosmic Rays," *Phys. Rev.*, **41**, 540–542, 1932. The paper, however, to which this statement refers is one by W. F. G. Swann and A. Bramley, *Phys. Rev.*, **41**, 393, 1932, read before the New Haven Meeting of the Am. Phys. Soc. on June 23, 1932. Incidentally it may be remarked that as stated in the paper, the order of magnitude given was 10^{10}, not 10^{9} as quoted by Williams. The value 10^{9} volts was calculated from the old classical theory.

radiation, suggests that an electron with energy greater than about 10^9 volts may, on account of radiative forces, not produce any ionization at all. In his argument Swann appears to assume that it is necessary to have a close classical-like collision in order to produce ionization. This, however, is not so. On the quantum theory, in the first place, nearly all the ionization takes place in distant collisions with impact parameter greater than atomic dimensions, etc."

In answer to Mr. Williams' criticism it must first be remarked that in the paper to which he refers no assumption is made as to the ionization occurring only in close encounters. The analysis is allowed to tell its own story, and is in complete harmony with those features to which Mr. Williams refers and which imply that it is mainly distant encounters which are effective in ionization. The real significance of the mathematical elements involved is this. Let us consider the first two terms in (3), the first term representing the perturbation field of the β particle, and the second term representing the modification in the whole wave mechanical story of the perturbation resulting from the incorporation of those elements, which in classical electrodynamics we spoke of as radiation reaction. In a crude way one may regard the $\partial\mathbf{E}/\partial t$ term as a radiation reaction arising from the electron suffering the ionization; but, from a wave mechanical angle, it is perhaps better to suppress such a picture born of classical ideas. Considering the contribution of the $\mathbf{E}$ term to the perturbation, this term contributes its main effect for encounters which are relatively distant not *because* it is small for those encounters, but because such encounters are much more frequent than are close encounters and are of much longer duration. It is true that closeness of encounter presents for the $\partial\mathbf{E}/\partial t$ term an advantage not possessed by the $\mathbf{E}$ term and arising from the *rapidity* of change of $\mathbf{E}$ with t at close encounters. The $\partial\mathbf{E}/\partial t$ is more potent in modifying the chance of ionization at a close encounter, but it has no power, for that reason, to enhance the importance of close encounter collisions. The main ionization, when it occurs at all, still occurs at more distant encounters. In these the $\partial\mathbf{E}/\partial t$ term does what it can; and, what it can do is represented by the results calculated in the paper by Bramley and myself. For

these reasons it is felt that the criticism raised by Mr. Williams cannot be substantiated.

A word must be added here concerning the occurrence of a on the left hand side of (1). The limitation of the coefficients of $\ddot{\mathbf{s}}$, $\dddot{\mathbf{s}}$, etc., to those given by classical electron theory, involving as it does the numerical assignment of those coefficients in terms of the classical electronic radius is a limitation which can hardly be justified in the light of a subsequent wave mechanical treatment. The numerical value of m/e stands in a different category from that of a; for it is determined directly from experiment without the invocation of any particular theory of electron structure or of the origin of the electronic equation of motion. The quantity a however depends for its evaluation upon m regarded as equal to $e^2/6\pi ac^2$, an expression bound up fundamentally with those details of the classical electronic theory which must be regarded as having evaporated in the realm of wave mechanics.[6] The existence of some left hand side to (1) of the form there given is a reasonable assumption provided that the coefficients are left as arbitrary. Their values must, in fact, be regarded as ultimately inherent in the fundamentals of the subject.

MORE GENERAL DISCUSSION IN RELATIVISTIC FORM.

In what follows we shall, as far as possible, avoid restricting the argument to any particular form of ψ equation, supposing only that we have *some* equation for ψ which is relativistically invariant. In this equation the vector and scalar potentials $\mathbf{U}$ and φ will occur. In general, however, the sole properties which need be invoked of them in order that they shall preserve the invariance of the equation is that U_x, U_y, U_z, $ic\varphi$, shall form a 4-vector. Such other properties as those which restrict them to satisfy the relations $\operatorname{div}\mathbf{U} = -(1/c)\partial\varphi/\partial t$; $\nabla^2\mathbf{U} - (1/c^2)\partial^2\mathbf{U}/\partial t^2 = 0$; $\nabla^2\varphi - (1/c^2)\partial^2\varphi/\partial t^2 = 0$, while important for endowing them with their usual significance in classical electromagnetic theory play no part in the story of

[6] There is no immediate reason why the terms in (1) involving third and higher order time derivatives should have magnitudes of the same order as those given by classical theory, a fact which opens up the possibility of experimentally detecting these terms in cases where the classical theory would have suggested that their effects would be beyond the limits of detection.

the invariance, even though they may play a part in the derivation of the ψ equation itself from certain assigned postulates. Thus, if in the fundamental ψ equation, $\mathbf{U}$ and φ be replaced by quantities obtained from them by operating with an invariant operator, the quantities so obtained, being still 4-vectors, will provide for the invariance of the new ψ equation.

Let $\mathbf{v}$ be the velocity of the centroid of the wave mechanical density distribution ρ which constitutes the electron. In Schroedinger's theory, $\rho = \psi\psi^*$. In other theories it may have other values. Let d/dt refer to differentiation with time as we follow a point moving with the velocity $\mathbf{v}$. Then,

$$\frac{d}{dt} = \frac{\partial}{\partial t} + (\mathbf{v}\cdot\text{grad}). \tag{5}$$

Let us choose for the operator referred to above

$$P = \left(1 - \alpha_1 k \frac{d}{dt} + \alpha_2 k \frac{d}{dt} k \frac{d}{dt} - \cdots\right)^{-1}, \tag{6}$$

where α_1, α_2, $\cdots$ etc. are constants, and where

$$k = (1 - v^2/c^2)^{-1/2}. \tag{7}$$

kd/dt when operating on a 4-vector gives a 4-vector even though $\mathbf{v}$ varies with time: and, P, which is a function of kd/dt gives a 4-vector when operating upon any 4-vector. We shall thus take for our modified ψ equation, the unmodified equation with $\mathbf{U}$ and φ replaced by

$$\mathbf{U}_1 = P(\mathbf{U}) \qquad \text{and} \qquad \varphi_1 = P(\varphi). \tag{8}$$

We shall presently discuss the apparently rather artificial use of the velocity $\mathbf{v}$, of the centroid, in determining the fundamental modification of the ψ equation.

Now, in a theorem given first in elementary form by P. Ehrenfest,[7] and later generalized in a very beautiful way by E. H. Kennard,[8] it appears that the ψ equation for an electron in an electric field $\mathbf{E}$ and a magnetic field $\mathbf{H}$ leads to the conclusion that the centroid of the electron moves with an

[7] P. Ehrenfest, *Zeitschr. für Phys.*, **45**, 455, 1927.

[8] E. H. Kennard, "Quantum Mechanical Motion of Free Electrons in Electromagnetic Fields," *Proc. Nat. Acad.*, **17**, 58–62, 1931.

acceleration $\ddot{\mathbf{s}}$ given by

$$\frac{m}{e}\ddot{\mathbf{s}} = \int\int\int \left(\mathbf{E} + \frac{[\mathbf{uH}]}{c}\right) \rho d\tau, \tag{9}$$

where the integral is taken throughout space. The velocity $\mathbf{u}$ is a velocity defined through the wave mechanical equation itself in such a way as to provide for the equation of continuity

$$\text{div } \rho\mathbf{u} + \partial\rho/\partial t = 0. \tag{10}$$

Kennard's demonstration was for a non-relativistic ψ equation; but it must result from any relativistic ψ equation which is to represent the facts (exclusive of course of radiation reaction), that,

$$\frac{m}{e}\frac{d}{dt}\frac{\dot{\mathbf{s}}}{(1 - \dot{\mathbf{s}}^2/c^2)^{1/2}} = \int\int\int \left(\mathbf{E} + \frac{[\mathbf{uH}]}{c}\right) \rho d\tau, \tag{11}$$

where $\dot{\mathbf{s}}$ represents the velocity of the centroid of the ρ distribution which represents the electron.[9]

If then the unmodified ψ equation leads to (11), the modified equation obtained by replacing $\mathbf{U}$ and φ by the values $\mathbf{U}_1$ and φ_1 given by (8) will, of necessity, lead to

$$\frac{m}{e}\frac{d}{dt}\frac{\ddot{\mathbf{s}}}{(1 - \dot{\mathbf{s}}^2/c^2)^{1/2}} = \int\int\int \left\{ P(\mathbf{E}) + \frac{[\mathbf{u}P(\mathbf{H})]}{c} \right\} \rho d\tau. \tag{12}$$

Since

$$\mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{U}}{\partial t} - \text{grad } \varphi; \qquad \text{and} \qquad \mathbf{H} = \text{curl } \mathbf{U}.$$

[9] The integrals on the right hand sides of (11) and (12) are in general not to be evaluated at constant time. There will, in fact, exist some system of axes in which the integral is to be evaluated at constant t'. Then, in any system moving relatively to that system with velocity $-v_0$, in which the measured time t is related to t' by $t' = \beta_0(t - vx/c^2)$, the integral must be evaluated at constant t' and so at variable t. Here the x axis is, of course, parallel to v_0. However, if τ represents the time for light to travel a distance comparable with that within which the greater part of the ρ distribution lies, v_0x/c is comparable with $v_0\tau/c$ in all important regions of the integration. Hence, if the change of any of the quantities under the integral in the time $v_0\tau/c$ is small, the integral may be regarded as evaluated at constant time t. The point is not one peculiar to wave mechanics, but exists in the old classical theory unless the electron is regarded as a point. The matter is naturally only of formal and not of practical significance.

Since $\mathbf{E}$ and $\mathbf{H}$ are sensibly constant throughout the electron, we may write [10]

$$\int\int\int P(\mathbf{E})\rho d\tau = P(\mathbf{E})$$

and

$$\int\int\int [\mathbf{u}P(\mathbf{H})]\rho d\tau = [P(\mathbf{H})\int\int\int \rho\mathbf{u}d\tau] = [P(\mathbf{H})\boldsymbol{\omega}],$$

where ρ is of course normalized to unity and $\boldsymbol{\omega}$ is the average value of $\mathbf{u}$, which is easily seen to be equal to $\mathbf{v}$, the velocity of the centroid.

Thus, (12) becomes

$$\frac{m}{e}\frac{d}{dt}\frac{\dot{\bar{\mathbf{s}}}}{(1 - \mathbf{v}^2/c^2)^{1/2}} = P(\mathbf{E}) + \frac{[P(\mathbf{H})\mathbf{v}]}{c}, \tag{13}$$

where $\mathbf{v}^2$ is synonymous with $\dot{\bar{\mathbf{s}}}^2$.

Let us now take a system of axes in which the centroid is at rest, and use zero subscripts to denote quantities measured in that system of axes. Since $\mathbf{v}$ is now zero, (13) becomes

$$\frac{m}{e}\frac{d\dot{\bar{\mathbf{s}}}_0}{dt_0} = P_0(\mathbf{E}_0), \tag{14}$$

where

$$P_0 = \left(1 - \alpha_1\frac{d}{dt_0} + \alpha_2\frac{d^2}{dt_0^2}\cdots\right)^{-1}.$$

Operating on both sides of (14) with P_0^{-1}, we obtain

$$\frac{m}{e}\left(1 - \alpha_1\frac{d}{dt_0} + \alpha^2\frac{d^2}{dt_0^2} - \cdots\right)\frac{d\dot{\bar{\mathbf{s}}}_0}{dt_0} = \mathbf{E}_0. \tag{15}$$

Let us now re-transform to a system of axes in respect to which the centroid moves with velocity $\mathbf{v}$, and let undashed letters refer to this system of axes. Then, since $\mathbf{E}_0$ is to be replaced by $k(\mathbf{E} + [\mathbf{vH}]/c)$, also $\dot{\bar{\mathbf{s}}}_0$ is to be replaced by $k\dot{\bar{\mathbf{s}}}$, and d/dt_0 by kd/dt, equation (15) yields

[10] We only make this assumption in going from the ψ equation to the equation of motion. The ψ equation itself is not limited by this restriction. In other words our aim is limited to making the ψ equation lead to the equation of motion for this restricted case.

$$\frac{m}{e}\left(\frac{d}{dt}k\dot{\mathbf{S}} - \alpha_1\frac{d}{dt}k\frac{d}{dt}k\dot{\mathbf{S}} + \alpha_2\frac{d}{dt}k\frac{d}{dt}k\frac{d}{dt}k\dot{\mathbf{S}} - \cdots\right) = \mathbf{E} + \frac{[\mathbf{vH}]}{c}, \quad (16)$$

which is the form of equation of motion desired, relativistic in form and containing the higher time derivatives of the motion.

The Artificiality in the Use of the Velocity of the Centroid in the ψ Equation.—While the utilization of $\mathbf{v}$ in the formation of the operator P which figures in the fundamental ψ equation, is perfectly permissible as regards logical consistency, it may well be criticized from the standpoint of artificiality. A more natural thing would be to use in place of $\mathbf{v}$, the velocity $\mathbf{u}$ of equation (10), which velocity varies, of course, in general, throughout the volume of the electron. If we do this, we can define our operator P in the same form as (6), but with $\mathbf{u}$ replacing $\mathbf{v}$ in the expression of d/dt, which now takes the form $\partial/\partial t + (\mathbf{u}\cdot\text{grad})$. Then, as before, we can proceed to replace $\mathbf{U}$ and φ by $P(\mathbf{U})$ and $P(\varphi)$ in the fundamental ψ equation; and, we can in fact get down to equation (12). A difficulty is then encountered, however, owing to the fact that $\mathbf{u}$ occurs as a variable under the integral sign, not only explicitly as it occurred before, but implicitly in P. It is consequently impossible to adopt the former artifice of getting P out of the integral to facilitate the subsequent operation on both sides of the equation by the operator P^{-1}. It is felt that the failure to produce the exact equivalent of (15) for the case in question is more formal than real; and, indeed, we can still produce that equivalent if we neglect terms involving ν^2, where ν is the velocity of an element of the $\psi\psi^*$ distribution relative to the centroid. This neglect of ν^2 will occur in two forms. The first when ν^2/c^2 is neglected in comparison with unity. The second is where, in the operator

$$P = \left(1 - \alpha_1\frac{d}{dt_0} + \alpha_2\frac{d}{dt_0{}^2} - \cdots\right)^{-1},$$

which has already experienced neglect of ν^2/c^2 compared with unity, we also replace d/dt by $\partial/\partial t + (\boldsymbol{\nu}\cdot\text{grad})$ when the operator multiplier is also multiplied by ν/c. This amounts

to supposing that α_1, α_2, etc., are so small that the terms which they control only have appreciable importance when the time rates of change in the field at a point are large, in which case the rates of change of field on a moving element as a result of its motion alone will be small in comparison unless ν is large. Moreover, the restriction involved in the neglect of ν terms in the foregoing is not one which limits the general ψ equation itself, but merely the types of field for which it is our intention to make that ψ equation yield an equation of motion of the form (16). It is in fact unreasonable to expect to produce that equation of motion for exceptional conditions of field or in completely exact form; for, as a matter of fact there is no *direct* experimental evidence to control the exact forms of the terms involving the higher time derivatives.

With the foregoing understanding, therefore, we start with (12) and refer it to a system of axes in which the centroid is at rest, so that it gives

$$\frac{m}{e}\frac{d}{dt_0}\dot{\bar{\mathbf{s}}}_0 = \int\int\int \left\{ P_0(\mathbf{E}) + \frac{[\mathbf{v}P_0(\mathbf{H})]}{c} \right\} \rho_0 d\tau_0, \qquad (17)$$

where

$$P_0 = \left(1 - \alpha_1 \frac{d}{dt_0} + \alpha_2 \frac{d^2}{dt_0^2} - \cdots\right)^{-1}, \qquad (18)$$

since ν^2/c^2 is neglected.

We must now investigate the contributions of the individual terms in the expansion of the operator P_0. Consider the integral I_1, given by

$$I_1 = \int\int\int \rho \frac{d\mathbf{E}}{dt} d\tau,$$

$$I_1 = \int\int\int \rho \frac{\partial \mathbf{E}}{\partial t} d\tau + \int\int\int \left(\rho u_x \frac{\partial \mathbf{E}}{\partial x} + \rho u_y \frac{\partial \mathbf{E}}{\partial y} + \rho u_z \frac{\partial \mathbf{E}}{\partial z} \right) d\tau$$

$$= \int\int\int \frac{\partial}{\partial t}(\rho \mathbf{E}) d\tau - \int\int\int \mathbf{E} \frac{\partial \rho}{\partial t} d\tau - \int\int\int \mathbf{E} \operatorname{div} \rho \mathbf{u}\, d\tau, \qquad (19)$$

where we have made use of Green's theorem in the last integral of (19), and have discarded the surface integral which vanishes at infinity. In view of (10), therefore,

$$I_1 = \int\int\int \frac{\partial}{\partial t}(\rho \mathbf{E}) d\tau = \frac{d}{dt} \int\int\int \rho \mathbf{E} d\tau.$$

In an exactly similar way, if

$$I_n = \int\int\int \rho \frac{d^n \mathbf{E}}{dt^n} d\tau$$

$d^{n-1}\mathbf{E}/dt^{n-1}$ plays the rôle of $\mathbf{E}$ in the above derivation, and we may show that

$$I_n = \frac{d}{dt} \int\int\int \rho \frac{d^{n-1}\mathbf{E}}{dt^{n-1}} d\tau$$

and so, by successive application of the theorem,

$$I_n = \frac{d^n}{dt^n} \int\int\int \rho \mathbf{E} d\tau.$$

Thus

$$\int\int\int \rho_0 P_0(\mathbf{E}) d\tau_0 = P_0 \int\int\int \rho_0 \mathbf{E}_0 d\tau_0. \qquad (20)$$

Again consider $\mathbf{J}$ given by

$$\mathbf{J} = \int\int\int [\mathbf{v} P_0(\mathbf{H})] \rho_0 d\tau_0.$$

Here we neglect the difference between d/dt and $\partial/\partial t$ in $P_0(\mathbf{H})$ since it is multiplied by $\mathbf{v}$. Further, we shall assume in accordance with all practical cases for which we need establish the equation of motion, that $\mathbf{H}$ is constant throughout the body of the charge distribution. Thus,

$$\mathbf{J} = \int\int\int [\overrightarrow{\rho_0 \mathbf{v}} P_0(\mathbf{H})] d\tau_0 = [\mathbf{W} P_0(\mathbf{H})],$$

where

$$\mathbf{W} = \int\int\int \rho_0 \mathbf{v} d\tau_0.$$

Thus, with ρ_0 normalized to unity, $\mathbf{W}$ is the average value of $\mathbf{v}$; and since the centroid is the origin, $\mathbf{W}$ is zero, and $\mathbf{J}$ is zero. Thus, using (20), equation (17) becomes

$$\frac{m}{e} \frac{d\dot{\mathbf{s}}_0}{dt_0} = P_0 \int\int\int \rho_0 \mathbf{E}_0 d\tau_0.$$

Since $\mathbf{E}_0$ is sensibly constant throughout the charge, this may be written

$$\frac{m}{e} \frac{d\dot{\mathbf{s}}_0}{dt_0} = P_0 \mathbf{E}_0.$$

This is exactly the same as equation (14). Just as before, therefore, we may operate on both sides of the equation with P_0^{-1} and obtain (15). We may then as before transform to a system of axes in which the centroid moves with velocity $\mathbf{v}$, and thus obtain (16), which is the desired equation. By suitable choice of α_1, α_2, etc., (16) may be given a wide range of generality including, as a special case, the equation which results from classical electrodynamics.

It will be observed that in simplifying the discussion in relation to the magnetic field by forming the equation of motion first in a system of axes in which the centroid is at rest, and then appealing to relativity to transform that equation to a new set of axes in which the former system moves with velocity $\mathbf{v}$, we have followed a procedure somewhat analogous to that adopted by Leigh Page [11] in the old classical electron theory, where he first formulates the equation of motion in a system of axes in which the electron is supposed to take the form of a sphere with zero velocity, and then appeals to relativity to obtain the equation of motion in any other system in which the electron has a velocity $\mathbf{v}$.

SIGNIFICANCE OF THE RESULTS.

The net result of the investigation has been to show that if we have a relativistic ψ equation which, through a theorem analogous to Kennard's theorem leads to the equation of motion (11), then by replacing $\mathbf{U}$ and φ in that equation by $\mathbf{U}_1$ and φ_1 as given by (8), where P has the form (6), we shall produce a ψ equation which will lead to an equation of motion such as (16). This equation contains the radiation reaction terms desired. The mathematics of the story is simplified by taking for d/dt, the expression (5), where $\mathbf{v}$ is the velocity of the centroid; and it represents a logical, consistent story. It is thought, however, that the expression (5) with $\mathbf{v}$ replaced by the variable $\mathbf{u}$ of the equation of continuity (10) represents a more reasonable hypothesis. It is a hypothesis which also leads to (16) with a few reservations believed to be of minor nature. Our primary object is to use the power of the modified ψ equation to realize (16) as evidence in favor of the truth of that ψ equation.

[11] Leigh Page, "Introduction to Electrodynamics," pp. 16–18, 24 and 53.

In taking for the ψ equation one modified from the original form by the procedure outlined above, we depart from the formal procedure of first constructing a Hamiltonian on the basis of the classical equations of motion and then formulating the ψ equation from that Hamiltonian by the usual rule. We have adopted a procedure which, in my judgment, forms a more fundamental basis for the ψ equation, the basis of choosing that equation so that through Kennard's theorem it shall lead to an equation of electronic motion which in the macroscopical wave mechanical sense shall agree with the facts, or at any rate to an equation of motion which represents our postulated starting point. The ψ equation must, of course, also provide for the other correlations expected of it, those concerned with line spectra and the like; but this it does in the ordinary way, as our procedure does not touch the essentials in this respect.

It is of course admitted that the procedure outlined above does not necessarily constitute a unique method of modifying the equation to a form such as would lead to (16). It seems a natural way, however, and one which adapts itself in the simplest manner to the mathematical forms of the equations and quantities concerned.

The net effect of the modification of the ψ equation which we have discussed is then to alter the perturbation potentials $\mathbf{U}$ and φ to the values $\mathbf{U}_1$ and φ_1, so that apart from the formal necessity of utilizing the velocity $\mathbf{u}$ occurring in (10), a necessity which would frequently evaporate in practice for small velocities, and which would not exist at all if we accepted equation (5), the analytical details involved in using the modified equation are not greatly different from those involved in using the unmodified equation.

It is realized that the spirit of the foregoing discussion is more in harmony with those aspects of wave mechanical theory which are a little out of date at the present time than it is in harmony with the more recent aspects contemplated in the Dirac theory. It is possible, however, that the ultimate differences concerned may be more formal than real.

BARTOL RESEARCH FOUNDATION OF
THE FRANKLIN INSTITUTE,
October 22, 1933.

Mind Over Matter?—R. G. TUGWELL, Assistant Secretary of Agriculture, writing about fraudulent or misleading advertising, describes a grim exhibit whose mute evidence spoke more dramatically than could any voice.

In the center of the exhibit stood a pint bottle of dark liquid which sells for $12. Surrounding the bottle was a medley of direct-mail leaflets claiming that the nostrum will cure diabetes. To the right was a bundle of letters—testimonials—written by persons who used the medicine and declared that they were cured. These testimonials are numbered. To the left was a batch of death certificates, also numbered. A comparison of each numbered testimonial with the correspondingly numbered death certificate showed that the name, the address and all descriptions were the same. Everyone of the persons who wrote testimonials died—and the doctors in every case certified that the cause of death was diabetes.

More interesting yet is that this $12 product was not manufactured by a pharmaceutical company but concocted, advertised and sold by a traveling shirt salesman who, failing to find enough people who wanted to send him to college, became more enterprising and built up a highly profitable business by preying on the misery and gullibility of diabetics. This particular product was made from a weed called "horse-tail."

C.

Vegetarian Ducks.—(U. S. D. A. Clip Sheet No. 799.) When the Bureau of Biological Survey was asked: "What do wild ducks eat?" one of the biologists started to find out through the interrogation of his acquaintances. A composite of the answers showed that ducks lived on bread, crackers, picnic leftovers and popcorn. The ducks observed resided in zoölogical gardens. In the wild state, popular opinion accorded the ducks a diet principally of fish with an odd bug or two for dessert.

An actual study of the wild ducks' living habits disclosed that 90 per cent. of their food is vegetation growing in or near the water. Less than one-tenth of the total food is animal matter and this small part consists chiefly of mollusks, insects, and crustaceans—seldom fish. Only the mergansers or fish ducks subsist chiefly on fish.

C.

EXPERIMENTS ON THE DISTRIBUTION OF LOW-ENERGY COSMIC RAYS IN THE ATMOSPHERE.

BY

W. E. DANFORTH and M. R. LIPMAN.

BARTOL RESEARCH FOUNDATION
Communication No. 85.

Insofar as a radioactively emitted β ray of energy, say three million electron volts, has a range of about only 1.4 grams per square centimeter and an electron of 10^7 volts energy corresponds, by extrapolation of β ray absorption curves, to a range of only about 4 gm./cm.^{2}, it is clear that there may exist in the atmosphere a wide range of secondary cosmic rays of an electron nature which would fail to reveal themselves in those counter experiments so far conducted, where the total amount of absorbing material associated with the counters is comparable with 4 gm./cm.^{2} at least. Electrons of energies between one million and ten million volts present an interesting field for investigation quite apart from their association with cosmic rays. Moreover, until high voltage technique advances still further, there is no ready means of producing these high energy electrons in the laboratory. For these reasons, and in connection with a plan for the general study of the properties of such electrons, as regards their scattering laws, etc., Dr. Swann has suggested the construction of very thin counter systems and has had such systems prepared by Mr. Nester in this laboratory. These Geiger counters were constructed as follows. A silver cylinder, 5 cms. long, 1.73 cms. diameter, and 0.0025 cm. wall thickness, with a 0.0075 cm. tungsten wire down the center, was surrounded by a glass cylinder. Mr. Nester has developed the art of drawing this cylinder down to a thickness of about 0.03 cm. for the whole length immediately surrounding the silver electrode. The tubes were cleaned with dilute nitric acid, evacuated, and filled with dry air at a pressure of about 7 cms. of mercury. A trace of iodine vapor was introduced with the air, in accordance with the procedure originally suggested by G. L. Locher for conditioning counting tubes.

The immediate problem attempted, was an examination of the absorption of the radiation under consideration by different slabs of absorbing material, where the term absorption is used to include rays which are turned aside through the act of scattering, etc.

Two counters were mounted, one directly above the other, with a distance of three centimeters between centers, and with a sheet of 0.0012 cm. tin between them for electrical shielding. Thus, in order to cause coincident discharges, an ionizing agent had to have sufficient energy to pass through three thicknesses of 0.0025 cm. of silver, three thicknesses of 0.03 cm. glass, and one thickness of 0.001 cm. tin, quite apart from any additional absorbing material used for investigation. The sum total of this absorbing material introduced by the counter system alone thus amounted to about 0.36 gram per sq. cm. The absorbing material was placed between the counters and the coincident discharges were recorded with the coincidence recording apparatus devised by Johnson and Street.[1] Without any absorbing material other than that used in the counters themselves, the counting rate was 1.5 per minute.

The absorbing material was brass of dimensions approximately that of a longitudinal section of one of the counters, and the procedure in the experiment was to take alternate half hour runs with and without the absorber. With an absorber of 4 grams per sq. cm., thirty readings of about thirty minutes each, gave a counting rate of 1.20 ± 0.03 coincidences per minute. Between each pair of the above readings, a similar reading was taken without the absorber, the average of these readings being 1.50 ± 0.03 coincidences per minute.

In a second experiment, an absorber of 2 grams per sq. cm. was used in an exactly similar manner, and the values obtained were 1.27 ± 0.03 with the absorber, and 1.42 ± 0.04 without.

The errors indicated above are the standard deviations, obtained by taking the root mean square of the individual deviations in the successive 30 minute intervals. These values agree within probable error with the standard deviation in a Poisson distribution obtained by taking the square root of the total number of counts.

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[1] Johnson and Street, JOUR. FRANK. INST., **215**, 239 (1933).

The slight difference between the counting rates without absorber for the two experiments is somewhat more than twice the standard deviation and hence an effect at least as great as this could occur by chance only once in some 50 to 100 times. A few weeks elapsed between these experiments so this effect may be due to some change in sensitivity of the apparatus such as a change in recovery time of one or both counters. The fact that both experiments conform individually to the Poisson law means that the relative values obtained in each are valid.

The smaller of our effects was about 4 times the standard deviation. The probability that an effect at least as great could occur by chance is of the order of magnitude of 0.0001.

Essentially therefore, the results of the experiments were as follows. With counters presenting inherently 0.4 gram per sq. cm. of absorbing material, the insertion of a 4.0 gm./cm.^{2} absorber between them reduces the counting rate by 20 per cent. $\pm$ 3 per cent. and a 2.0 gm./cm.^{2} absorber reduces it by 10 per cent. $\pm$ 3 per cent.

If we suppose that the ionizing agents responsible for the double coincidences are electrons, or positrons, the curve for the range of a β particle versus its energy then tells us that the counters were sensitive to rays having energies greater than 1,000,000 volts. The results of the experiment then indicate that, of all electrons or positrons in the atmosphere of the room* having energies greater than 1,000,000 volts, one-fifth have energies less than 10,000,000 volts, and one-tenth have energies less than 5,000,000 volts. The rays in the lower tenth probably include both cosmic ray secondaries, and electrons of radioactive origin, such as β particles, and secondaries from γ rays.

It is interesting to make an estimate of the number of radioactive particles having energy greater than 1,000,000 volts, and thus being capable of recording on the apparatus. We have carried through a calculation of this contribution to the intensity based on the data that air contains 1 to 2 atoms of radon and 1 to 2 times 10^{-4} atoms of thoron,[2] and that

* One must realize that owing to electrons and positrons emitted from the ceiling and walls of the room, the conditions are not strictly comparable with those in the open atmosphere.

[2] *Handbuch der Experimental Physik*, XXV, p. 270.

natural rock contains 10^{-6} to 10^{-5} grams per gram of uranium and thorium.[3] The intensity of electrons of energy greater than 1,000,000 volts arising both as β particles and as γ ray secondary electrons was calculated for a room of simplified geometry. We considered a hemispherical shell of rock below the plane of whose base rock extends to infinity. The shell contains air and, above the plane of the base, is surrounded by air to infinity. Then, using radioactivity data concerning production of high energy β particles and γ rays by the various members of the several disintegration series involved, we calculated roughly lower and upper limits to the expected intensity. To conserve space we will omit the rather cumbersome details and will merely state the results. We found that the number of electrons of energy greater than 1,000,000 volts and of natural radioactive origin can reasonably be expected to lie between 6×10^{-4} and 80×10^{-4} electrons per unit solid angle per square centimeter per second.

Comparing this with the cosmic ray intensity of 0.01, we see that the electrons, of energy over 10^6 volts from radioactive material, may number from 6 per cent. to 80 per cent. of the cosmic ray intensity as observed with the usual counters. Since, however, the contribution of radioactivity to radiation of energy greater than 5×10^6 volts is negligible, all counts from radioactive sources are eliminated by the 2 gm./cm.^{2} absorber. We observed that inserting the 2 gm./cm.^{2} absorber decreased the counting rate by about 10 per cent. It is made evident by the calculation, that radioactivity is capable of accounting for this fraction. The 4 gm./cm.^{2} absorber, however, eliminated about 20 per cent. of the radiation, showing that about 10 per cent. lies above 5×10^6 volts, and below 10^7 volts. In other words, a band of radiation exists with energy above the radioactivity domain, but below that capable of affecting ordinary counters.

The interpretation of experiments of this type is complicated by scattering phenomena. Inserting the absorbing block may affect a ray in four ways: (*a*) a ray may be stopped entirely or have its energy reduced below that value necessary to discharge the lower counter, (*b*) a ray which would enter

[3] Knopf et al., "The Age of the Earth" (National Research Council), p. 218.

the lower counter may be deviated away, (*c*) a ray which is not directed toward the lower counter may be deviated into it, (*d*) a ray which is not directed toward the counter may eject from the absorbing material another ray which will pass through the counter. An observed decrease in counting rate is, therefore, the algebraic sum of these four contributions. Effects (*a*) and (*b*) tend to decrease the counting rate, while (*c*) and (*d*) tend to increase it. Considering processes (*b*) and (*c*), the experiments of Anderson [4] tell us that 5 degrees is a reasonable average angle of scattering for cosmic rays which penetrate 11 mm. of lead. This angle will probably be smaller in the case of our 4 gm./cm.^{2} absorber. Hence it seems that changes brought about by this type of scattering are confined to a narrow region about the boundary of the lower counter and that the number scattered in will very nearly cancel the number scattered out. The remaining effect (*d*) can be estimated using a figure kindly supplied by T. H. Johnson. On the basis of experiments performed by him and J. C. Street,[5] it is computed that the probability of a cosmic ray ejecting a secondary in unit solid angle on passing through 2.2 cm. of lead is 0.016. This value corresponds to a range of angles in the neighborhood of 45° and is roughly independent of angle. Assuming proportionality to density this value reduces to 0.004 for material of 4 gm./cm.^{2}. In computing an upper limit for the effect of this process on our experiment we multiply this value by the maximum solid angle between our absorber and lower counter (about 4) giving us 0.016. Representing this probability by P, an easily verifiable deduction leads to the formula $f_0 = (f + aP)/1 + aP$ where f is the observed fractional decrease, f_0 the true fraction stopped, and a the ratio between the number of rays through the upper counter and absorber but not through the lower counter, to the number through both counters. This ratio is about 2. The above formula then sets an upper limit for the effect of scattering at about 3 per cent. which happens to be the limit of accuracy of our measurements.

Summary.—Experiments with thin-walled Geiger-Mueller counters lead to the conclusion that the energy spectrum of

[4] Anderson, *Phys. Rev.*, **43**, 381 A (1933).

[5] Street and Johnson, *Phys. Rev.*, **42**, 142 L (1932).

cosmic ray secondaries extends down to at least 5×10^6 electron volts, and that the intensity in rays per unit solid angle per square centimeter per second, between 5×10^6 and 10^7 volts, is roughly one-eighth of the total intensity above 10^7 volts.

Thanks are due to Dr. Swann for helpful suggestions and criticism.

MEASUREMENT OF THE IONIZATION PER CENTIMETER OF PATH BY INDIVIDUAL SECONDARY COSMIC RAYS.[1]

BY

W. F. G. SWANN.

BARTOL RESEARCH FOUNDATION

Communication No. 82.

Introduction.—The fact that secondary cosmic rays contain electrons and positrons of energies higher than those observed in radioactive substances causes the investigation of their ionization per centimeter of path to be a matter of considerable interest, particularly as indirect measurements of this number have given values ranging all the way from 36 to 165 for the ions produced per centimeter of path at atmospheric pressure, in air, for example.[2] The experiments here described constitute a direct attack upon the problem in that the plan involves the actual measurement of the ionization of the individual rays. The accuracy at present is not high, but modifications of the method designed to secure a better approach to precision measurements have been made and the results of such measurements will be reported in due course. The accuracy of the present measurements is sufficient to bring to light certain interesting features, to establish the ionization per centimeter of path as about 90 ions per centimeter at atmospheric pressure in argon (which would correspond to about 60 for air, rather than about 150), and to demonstrate the importance of double and triple rays in having contributed to the reason for the higher figure found by certain former observers.

[1] Presented in preliminary form before the American Physical Society, at the New York meeting, February 24, 1933, and in greater detail before The American Philosophical Society, at Philadelphia, April 22, 1933. A complete account of the investigation has been published in extenso in the Physical Review for Dec. 15, 1933.

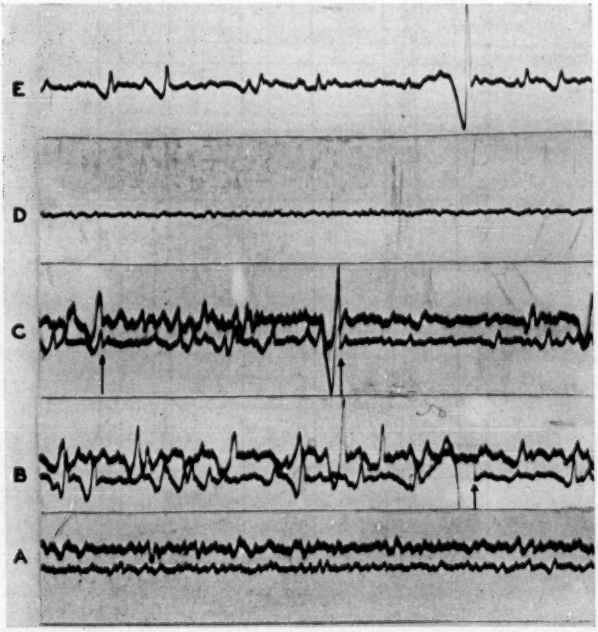
[2] By counting the individual drops in a cloud chamber, values of the order 40 ions/cm. in air have been obtained by D. Skobelzin, by G. L. Locher, and by C. D. Anderson. On the other hand, from counter data combined with the magnitude of the total ionization per second in a vessel, W. Kolhörster and L. Tuwin, working jointly, also W. Messerschmidt, and T. H. Johnson, have obtained values ranging from 110 to 165 ions/cm.

Experimental Procedure.—A vertical cylinder 15 cms. and 7.5 cms. in diameter was provided with a central insulated rod which was connected to an FP–54 pliotron, which in turn was connected to a four stage amplifier operating a short period galvanometer which recorded upon moving photographic paper. The cylinder was filled with argon in the main experiments, to a pressure of 5 atmospheres in some cases and 10 atmospheres in others. A potential difference of 1100 volts was applied between the outer cylinder and the rod, so that the ions produced by an individual ray were swept across and caused to record upon the galvanometer. For the purposes of securing additional information, two systems of the foregoing kind were employed in some of the experiments. The two cylinders were arranged end to end, and the galvanometers were caused to record upon the same photographic paper.

The Records Obtained.—The complete records obtained involved many thousands of counts and it is naturally only possible to give typical illustrations. Such are shown in Fig. 1, in which the galvanometer spot should be regarded as travelling from right to left. Fig. 1, *E*, represents a portion of a record taken with a cylinder 30 cms. long and 4 cms. in diameter, filled with argon to 200 lbs. pressure. It is characterized by one very long kick, which possibly represents an alpha particle. The medium sized kicks are secondary cosmic ray kicks. Fig. 1, *D*, is a trace for the same cylinder at atmospheric pressure and serves to show an upper limit for the magnitude of the background disturbances, which in part, at any rate, are produced by the secondary cosmic rays. The sensitivity in the cases *D* and *E* is such that one millimeter kick on the original record corresponds to the instantaneous application of 4.0×10^{-5} volts to the central system. Fig. 1, *C* and *B*, represents simultaneous traces for two cylinders in line each cylinder being 15 cms. long and 7.5 cms. in diameter, filled with argon to 70 lbs. pressure. The voltage sensitivity was about twice that for cases *E* and *D*. The arrows in case *C* indicate simultaneous kicks, and represent cases where a ray has passed through both cylinders. However, simultaneous kicks of this kind are unreliable of interpretation on account of the production of spurious coincidences by different rays which happen to coincide very nearly in time in

the two cylinders. They are, however, reliable when used in the sense of *upper limits* to the number of real coincidences; and it is only in this sense that we shall use them. In Fig. 1, *B*, the arrow indicates a portion of the trace of an alpha particle for which the kick went completely off the photo-

FIG. 1.

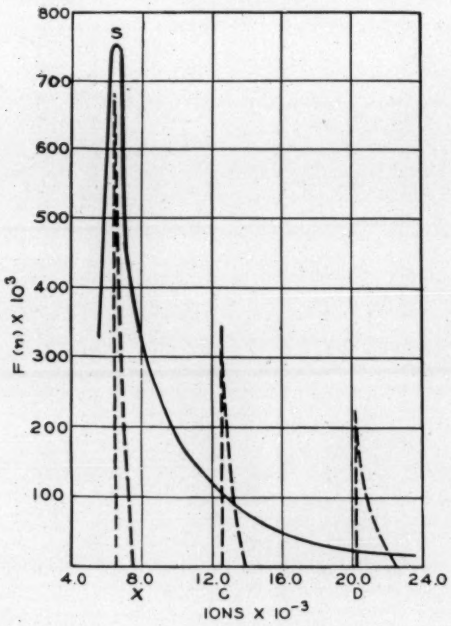


graphic paper. Fig. 1, *A*, represents the same cases as *B* and *C* except that the pressure was one atmosphere.

Analysis of the Results.—The full curve of Fig. 2, *A*, shows, for a cylinder 15 cms. long and 7.5 cms. in diameter, filled with argon at 5 atmospheres pressure, the values of $F(n)$ plotted

against n, where $F(n)$ is the coefficient of dn in the expression for the number of kicks in 2,000 seconds which correspond to a production of ions between n and $n+dn$ in number. The abscissæ are the values of n. The curve represents the results of 2,700 observations of kicks, about half of all the observa-

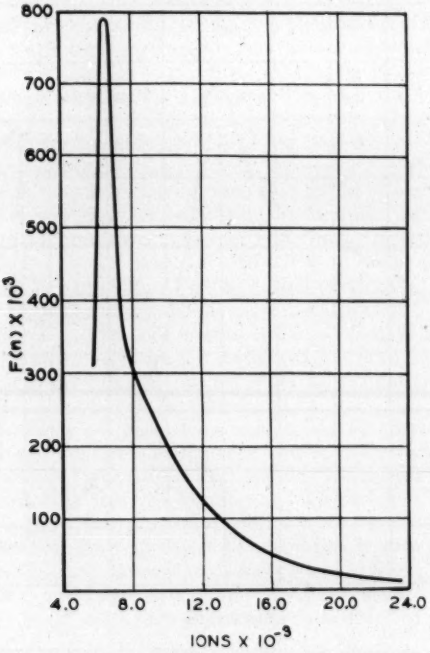
FIG. 2A.



tions taken. Fig. 2, B, represents the results of the other half of the observations. The two are given merely to show the extent of reproducibility of the results. The curves are not continued back to $n = 0$ because for the smaller values of n the observations become obscured by the background disturbances of the FP–54 tube. As far back as they are drawn

they are definite and reproducible to the extent indicated. If all of the rays were single rays of the same kind, the curve should correspond in form to the curve representing $f(l)$, the coefficient of dl in the expression for the number of rays which

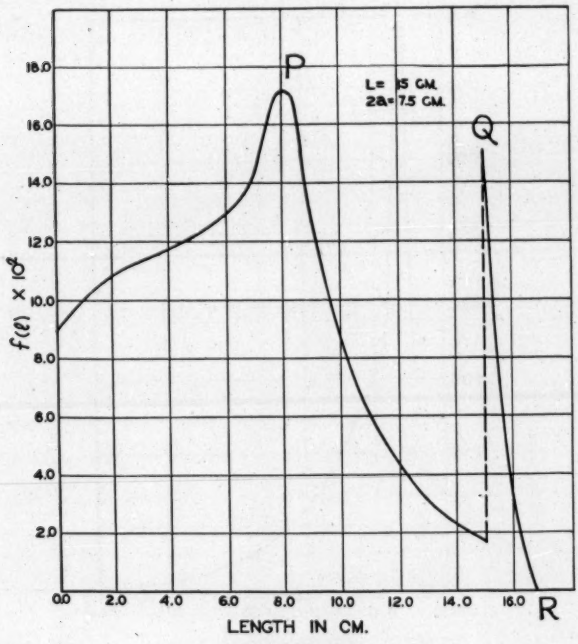
FIG. 2B.



travel lengths between l and $l + dl$ in the cylinder for which the observations represented in Fig. 2, were taken. In Fig. 3, the theoretical curve is shown. The complete derivation of the formulæ upon which this curve is based is given by the writer in a paper "The Distribution of Cosmic Ray Paths in a Vertical Cylinder," published in the JOURNAL OF THE

FRANKLIN INSTITUTE, 216, pp. 559–581, 1933. The constant A incorporated with $f(l)$ in the ordinates is the number of rays falling per second per unit vertical solid angle per unit of area perpendicular to the vertical per second.[3] Small a is the

FIG. 3.



radius of the cylinder. The points P, Q, and R, correspond respectively to the diameter of the cylinder, the height of the cylinder, and the longest line which can be drawn in the cylinder. The point Q is preceded by an actual discontinuity

[3] Its value in Fig. 3 is taken as 0.72×10^{-3}, which value was obtained by Dr. Gordon Locher by means of Geiger counters in an adjoining room on the same floor of the laboratory as that in which the experiments were conducted.

in the curve. The theoretical curve is drawn under the assumption that the intensity of the rays is proportional to $\cos^2\theta$, where θ is the angle from the vertical, this law being an empirical expression of the facts of counter measurements.

A full analysis of the information given by Figs. 2 and 3 leads to the conclusion that the peak at S of Fig. 2 is to be associated with the point Q of Fig. 3. The absence of the peak P in Fig. 2 arises merely from the fact that owing to tube background it is impossible to continue the experimental curve into the region of this peak. In connection with the foregoing statement it is of interest to note that were D of Fig. 2, associated with the abscissa of Q of Fig. 3, there should be an experimental contribution to Fig. 2, represented by the dotted curve at D. Such a contribution could not have been missed since all errors of experiment tend to increase, rather than diminish, the number of apparent kicks in the records. The association of the abscissa of Q with C, Fig. 3, would again call for a peak as represented by the dotted curve at C. As we proceed along the experimental curve from the right, the first and only peak to be encountered is that at S and this is the peak to be associated with the abscissa of Q. Such an association leads to the value 89 ions per centimeter of path in argon, reduced to atmospheric pressure.

In the complete paper reasons are given for showing that the main portion of the experimental curve to the right of S is to be explained by multiple rays; and the experiments with the two cylinders in line give significant information in forming this decision. It is possible to estimate the ionization produced by these multiple rays and to compare it with that due to the single rays. From such a comparison it is seen that the multiple rays contribute two thirds of the total ionization observed in the cylinder and constitute one-third of the total number of ionizing entities, groups and singles. By consideration of the effects of the multiple rays, it is possible to reconstruct the high values obtained for the *apparent* ionization per centimeter of path obtained by former observers who have deduced their values from ionization measurements combined with counter data, and from fluctuation measurements.

The curves for $F(n)$ were also obtained for a cylinder 30 cms. long and 4 cms. in diameter for argon, oxygen and

nitrogen. By a comparison of these curves and utilizing the value 89 ions per centimeter of path already obtained for argon, the values 57 for oxygen and 61 for nitrogen are found for the ionization per centimeter of path at atmospheric pressure in these gases.

The writer wishes to acknowledge the services of his Research Assistant, Mr. W. E. Ramsey, who has made the actual observations cited in this paper.

SUBHARMONIC FREQUENCIES PRODUCED IN NON-LINEAR SYSTEMS.

BY

W. M. GOODHUE, S.M.,

Instructor in Electrical Engineering, The Harvard Engineering School, Cambridge, Mass.

INTRODUCTION.

It is well known that if a sine wave of current or voltage is distorted by a device having a non-linear characteristic, the distorted wave contains harmonics and may contain even a unidirectional component. Typical examples of this are the magnetizing current of transformers with a sine wave of impressed voltage; output waves of vacuum tubes, with sinusoidal input waves, when the tube operates on the curved portion of its plate-current—grid-voltage characteristic; corona current, etc. But it is not so well known that the converse is true, that is, if a wave containing no component whatsoever of fundamental frequency, but containing only higher harmonics, operates through a non-linear device, a fundamental component may be produced, while at the same time a change of amplitude of the original harmonics may occur and harmonics of new frequency may appear.

This phenomenon was first considered by the author when the results of some high-voltage bridge measurements on dielectrics in which ionization existed were brought to his attention. Ionization doubtless produced harmonics in one bridge circuit whereas a sine wave of current flowed in the other (1). The tuned galvanometer responded only to the fundamental and therefore should not be affected by the harmonics. But it was found that when the vacuum-tube amplifier, used to increase the sensitivity of the galvanometer, was connected in circuit, the residual harmonics actually did cause deflections of the galvanometer, resulting in false balances. At times the error in balance was as great as 7 per cent. It seemed probable that this result could be caused only by the conversion, at least in part, of the harmonics into the fundamental. Careful investigation proved this assumption to be correct.

Search of the literature showed that this phenomenon appeared to be little known. In the study of a capacitance bridge, Ferguson and Bartlett (2) noticed a similar effect, but it was caused by harmonics in the supply oscillator. They attributed the effect to modulation and did not attempt to analyze the phenomenon even for a single stage of amplification. The fact that the phenomenon did not appear to be either well known or well understood led the author to make a careful study and analysis of it and to place it on what appears to be a rational basis. Moreover, the effect appears to be distinct from "modulation" effect as that word is ordinarily used in communication work.

In the demonstration which follows, it is shown that a *single* vacuum tube (or other non-linear device) operating under the simplest circuit conditions is capable of converting a wave consisting of only a *third* and a *fifth* harmonic into a wave yielding a substantial fundamental component, as well as higher harmonics. The better known theory of detection of a modulated wave would show under these conditions (single tube, detector action) *only a second harmonic* rather than a fundamental component. A second tube, making a two-stage amplifier, can reduce some of this second harmonic to fundamental owing to interaction with the third harmonic, again due to detector action.

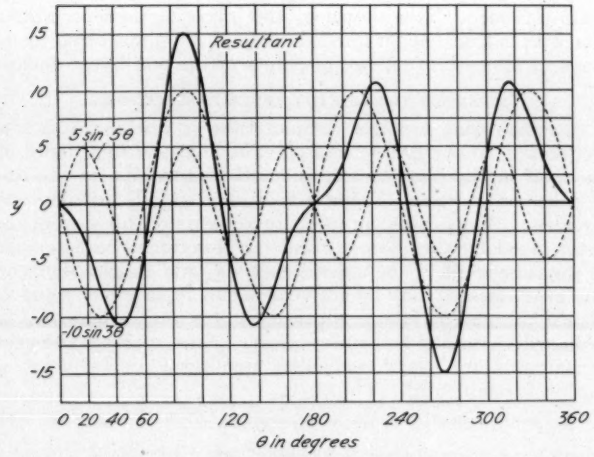
Thus with the usual detector action (second order distortion) and its application to modulated waves (containing two or more frequencies), two tubes are required to produce a fundamental by the detector-modulation effect. It might therefore be assumed that no fundamental would be obtained with a single tube since the tuned galvanometer is insensitive to the resulting second harmonic. Actually, as will be shown, such a single-stage amplifier is very likely to develop a fundamental wave in its output. Therefore, the phenomenon cannot be one of "modulation" as the term is usually understood.

It will also be shown that other phenomena *occurring with a single tube*, such as amplification and detection, involve correction terms, usually neglected. Sometimes these terms amount to 9 per cent. or more of the value expected from the ordinary linear and square law analyses of amplification and detection.

RELATION OF PERIOD OF RESULTANT WAVE TO HARMONIC PERIODS.

The following relationship among harmonic periods and the fundamental period is essential to an understanding of the phenomena. *A wave consisting of two harmonic components has a period equal to that of the fundamental, although the resultant wave itself contains no fundamental component whatsoever.* For example, consider in Fig. 1 the wave $y = A \sin 3\theta$

FIG. 1.



Wave containing no fundamental component, yet having the *period* of the fundamental component.

$+ B \sin 5\theta (A = -10$ and $B = 5)$. The two components, $A \sin 3\theta$ and $B \sin 5\theta$, are shown dotted and have respectively 1/3 and 1/5 the period of that of the fundamental component $\sin \theta$. From inspection it may be seen that the resultant wave repeats itself only at periods equal to the period of the fundamental, $\sin \theta$, even though it contains *no fundamental component* $\sin \theta$. Thus, if a wave is composed of harmonics and contains *no* fundamental component whatsoever, the period of the resultant wave is still that of the *fundamental*. Thus the period of a *wave* and the period of its lowest-frequency sinu-

soidal *component* may differ, a fact which has not been well understood, and which underlies the phenomena discussed in this paper.

When the wave of Fig. 1 becomes distorted, as by some non-linear circuit, it still retains the period of $\sin\theta$, but in addition usually contains an actual fundamental component $C\sin\theta$. That is, by distortion one may *change* the *amount* of fundamental component in *any* wave. Hence the wave shown in Fig. 1 is merely a special case for which the amount of fundamental is zero. It is shown by the following demonstrations that this is true, except for certain specially shaped characteristics or for certain operating points of the non-linear device.

EXPANSION THEOREM FOR MODERATE AMPLITUDES.

Assume that a *single* vacuum tube is working at a low frequency, 60 cycles for example, and that the impedance of the load in the plate circuit is small compared with the impedance of the tube. (This is typical of tetrode and pentode circuits.) The output-input characteristics of this system are determined by the plate-current—grid-voltage characteristic of the tube itself. The usual symbols i_p and e_g (plate current and grid voltage) may for convenience be replaced by y and x. Hence the characteristic is given by $y = f(x)$, where $f(x)$ is ordinarily assumed to be non-linear. Now apply to the grid circuit an e.m.f. wave containing two harmonic frequencies, but no fundamental. Thus,

$$\Delta x = E_1 \cos(m\theta + \alpha) + E_2 \cos(n\theta + \beta), \qquad m > n \quad (1)$$

where θ = independent variable, angle $\theta = \omega t$
ω = 2π times the fundamental frequency
t = time, seconds
α, β = phase angles (constants)
m, n = harmonic numbers.

The Fourier series for the output, Δy, may be determined as follows:

Applying Taylor's Theorem:

$$\Delta y = a(\Delta x) + b(\Delta x)^2 + c(\Delta x)^3 + d(\Delta x)^4 + \cdots, \quad (2)$$

where a, b, c and d are the well-known Taylor coefficients depending on the first four derivatives of the function $y = f(x)$,

divided by the number corresponding to the term factorial, that is $(1/K')/(d^k y/dx^k)$.

If equation (1) is substituted in (2), the terms combined and certain trigonometric transformations made, neglecting in (2) terms of higher order than the third, the following general Fourier series containing a finite number of terms is obtained (see Appendix for complete analysis).

$\Delta y =$	Frequency evolved $m = 5; n = 3$
$+\frac{b}{2}(E_1^2 + E_2^2)$	0
$+\frac{3}{4}cE_1E_2^2 \cos[(2n - m)\theta + (2\beta - \alpha)]$	1
$+ bE_1E_2 \cos[(m - n)\theta + (\alpha - \beta)]$	2
$+ aE_2\left[1 + \frac{3}{2}\frac{c}{a}\left(\frac{E_2^2}{2} + E_1^2\right)\right] \times \cos[n\theta + \beta]$	3
$+ aE_1\left[1 + \frac{3}{2}\frac{c}{a}\left(E_2^2 + \frac{E_1^2}{2}\right)\right] \times \cos(m\theta + \alpha)$	5
$+\frac{b}{2}E_2^2 \cos[2(n\theta + \beta)]$	6
$+\frac{3}{4}cE_2E_1^2 \cos[(2m - n)\theta + (2\alpha - \beta)]$	7
$+ bE_1E_2 \cos[(m + n)\theta + (\alpha + \beta)]$	8
$+\frac{c}{4}E_2^3 \cos[3(n\theta + \beta)]$	9
$+\frac{b}{2}E_1^2 \cos[2(m\theta + \alpha)]$	10
$+\frac{3}{4}cE_1E_2^2 \cos[(2n + m)\theta + (2\beta + \alpha)]$	11
$+\frac{3}{4}cE_1^2E_2 \cos[(2m + n)\theta + (2\alpha + \beta)]$	13
$+\frac{c}{4}E_1^3 \cos[3(m\theta + \alpha)]$	15

The numbers (0, 1, 2, 3, 5, etc.) following each term give the frequency or harmonic number which the term represents when, as an example, $m = 5$, $n = 3$.

The first term (0) is the direct-current term of detector action and equals b times the square of the r.m.s. value of the impressed wave.

When $f(x)$ is a power series to the third order term inclusive, the preceding analysis shows that a third and a fifth harmonic may interact to give all harmonics through the 15th, with the exception of the 4th, 12th and 14th.

The most significant term, however, is 1, that is $3/4\ cE_1E_2^2 \cos[(2n - m)\theta + 2(\beta - \alpha)]$. With $m = 5$ and $n = 3$, this term yields the fundamental component, which probably caused the false balance in the bridge circuit.

It will be noticed that it is a *third order* effect and that *both* E_1 *and* E_2 *must exist* in order to produce the fundamental component.

The next term 2, that is, $bE_1E_2 \cos[(m - n)\theta + (\alpha - \beta)]$ is important in that it gives detector action (for a modulated wave). If $m = 5$ and $n = 3$, this yields a second harmonic.

Then come the two *amplification* terms. In the tabulation, term 5 is $aE_1[1 + 3/2\ c/a\ (E_2^2 + E_1^2/2)] \cos(m\theta + \alpha)$ and term 3 is $aE_2[1 + 3/2\ c/a\ (E_2^2/2 + E_1^2)] \cos(n\theta + \beta)$. They are so-called because each gives the ordinary amplification *plus* a correction term.

Typical numerical values follow:

With an input voltage $\Delta x = 1 \cos 3\theta + 0.5 \cos 5\theta$ impressed on a 201a vacuum tube, grid bias $= -3$ volts, plate volts $= 40$,

$$\Delta y = \frac{1.47}{1000}[20.4 + 2.00\cos\theta + 16.3\cos 2\theta + 106\cos 3\theta + 54.5\cos 5\theta + 16.3\cos 6\theta + 1.00\cos 7\theta + 16.3\cos 8\theta + 1.33\cos 9\theta + 4.07\cos 10\theta + 2.00\cos 11\theta + 1.00\cos 13\theta + 0.167\cos 15\theta]. \quad (3)$$

The resulting fundamental component of $2.00 \cos\theta$ as compared with $106 \cos 3\theta + 54.5 \cos 5\theta$, is of appreciable magnitude. It is to be noted that these relations are for single-stage amplifiers. With more than one stage, the several cumulative

amplifications and other associated reactions may tend to give a much larger percentage yield of fundamental.

As a second example, consider the existence of an even harmonic in the input, $\Delta x = 1 \cdot \cos 2\theta + 0.5 \cos 3\theta$. Then

$$\Delta y = \frac{1.47}{1000}[20.4 + 18.3 \cos\theta + 106 \cos 2\theta + 54.5 \cos 3\theta + 17.3 \cos 4\theta + 16.3 \cos 5\theta + 5.4 \cos 6\theta + 2.00 \cos 7\theta + 1.00 \cos 8\theta + 0.167 \cos 9\theta]. \quad (4)$$

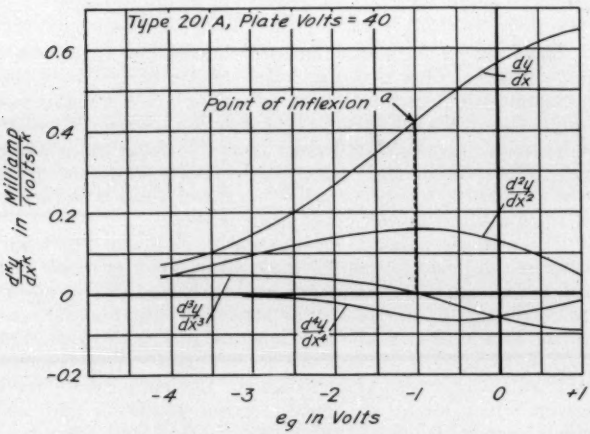
Here the resulting fundamental component $18.3 \cos\theta$ is much greater, since a second order effect, detection, is also important ($16.3 \cos\theta$ with detection alone). The foregoing examples show that the third order correction term in the theory of detection of a modulated wave cannot be neglected as a rule. Also, it is not generally appreciated that the efficiency of the tube as a detector may actually be greater than is ordinarily assumed if second order effect alone is used.

This example suggests the cumulative reactions which may occur in a multi-stage amplifier, i.e. the second harmonic generated by the first stage may interact with the third harmonic, obtained by amplification, so as to yield a fundamental component in addition to the fundamental produced in the first stage and amplified through the second stage. Experimental studies show in corona and ionization a tendency toward rectification which might introduce a second harmonic and also direct current into the input wave. Second and other even harmonics may also be introduced between stages by the direct-current component of plate current flowing in the primary of the amplifying transformer. (See example below for an iron alloy.)

Certain peculiarities of the characteristics should be noted. The original characteristic $y = f(x)$, of the 201a vacuum tube, roughly approaches a straight line as the grid voltage becomes positive, a fact which is well known. *Therefore the curve* dy/dx (Fig. 2), *giving the slope of the characteristic, flattens out as the grid voltage becomes positive,* since the slope of a straight line is constant. In the other direction, towards negative grid bias, both y and dy/dx approach zero *asymptotically. Therefore the curve of* dy/dx *should have a point of inflexion, a,* shown in Fig. 2.

The practical importance of this point of inflexion is great, since it means not only that d^2y/dx^2 will have a maximum, but also that d^3y/dx^3 will pass through zero at this point, with corresponding effects on the second and third Taylor coefficients. If point a be chosen as the point of operation, the production of fundamental from combined third and fifth harmonics will

FIG. 2.



Curves for derivatives of consecutively increasing order.

be almost nil; however, operation point a is favorable to detector action, and to the production of fundamental from second and third, or from third and fourth harmonics.

The fourth order slope, d^4y/dy^4, gives a means of estimating the error due to neglecting the fourth term of the expansion. This error is smaller to the left of the point of inflexion (Fig. 2) and also dy/dx is smaller. Thus the most favorable point of operation is probably to the left of the point of inflexion a.

MAGNETIC DISTORTION.

From the mathematical nature of these subharmonic phenomena it is to be expected that they may also be produced in

electric circuits linked with magnetic materials, since such circuits are obviously non-linear. Magnetic materials are used not only in power apparatus, such as transformers and induction motors, but also in the magnetic couplings of amplifiers, in filters, and in the vibration galvanometer, elements of a bridge detecting system. Hence, magnetic materials may be responsible in part for the production in the detecting system of a fundamental component from higher harmonics. Magnetic effects will be complicated by hysteresis loop effects and by eddy currents, and perhaps even by time lag in the magnetic properties of the material.

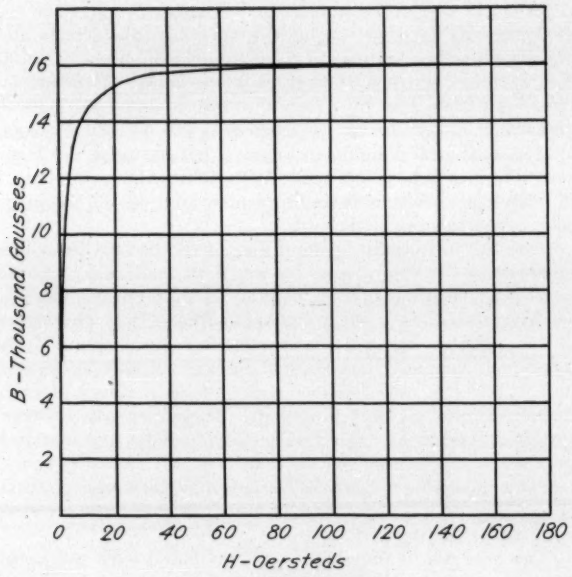
In order to obtain a general idea of the process by which subharmonics are produced by magnetic materials, assume that ideal conditions prevail, that is, the material is a modern low hysteresis alloy such as hipernik,[1] whose B–H characteristic is given in Fig. 3. The hysteresis loop of this alloy is very much narrower than that of the best silicon transformer steel. Also the material is operated over a range of high magnetizing forces, thus minimizing the comparative effect of hysteresis variations. To reduce eddy currents, the material may be made into very thin laminations, and a low frequency may be employed. Under these conditions, the magnetization curve shown in Fig. 3 may be assumed without large error to hold over the entire cycle.

The analysis of the electric circuit linked with magnetic materials, when applied to practical operating conditions, is further complicated by the fact that neither a definite impressed internal voltage on the winding linking the material nor a definite impressed current may prevail. It is recognized that whether the input impressed quantity be taken as current or voltage, the output is distorted, in general, when compared with the input. To simplify the analysis, an assumption will be made as to whether the impressed current or impressed voltage is definitely fixed.

Assume a core, of cross-section A sq. cm., wound with N turns, and neglect the resistance of the winding. Let the impressed voltage be

[1] "Permeability of Hipernik Reaches 167,000," by T. D. Yensen, published in the *Electric Journal* for June, 1931, pp. 386–388.

FIG. 3.



B-H characteristics of Hipernik.

$$e = E_1 \cos(3\theta + \alpha) + E_2 \cos(5\theta + \beta), \qquad (5)$$

where $\theta = \omega t$

$\omega = 2\pi$ times the fundamental frequency

$\alpha, \beta =$ phase angles (constant).

$$e = +N\frac{d\varphi}{dt}; \qquad \therefore \varphi = +\frac{1}{N}\int e\,dt. \qquad (6)$$

The flux density, $B = \varphi/A$.

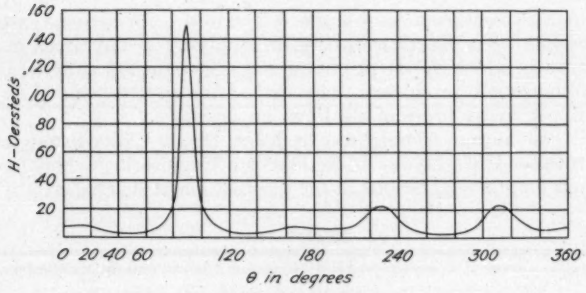
By integration,

$$B = \frac{E_1}{3AN\omega}\sin(3\theta + \alpha) + \frac{E_2}{5AN\omega}\sin(5 + \beta) + \textit{constant} \qquad (7)$$

Let $\frac{E_1}{3AN\omega} = -1000$, $\frac{E_2}{5AN\omega} = +1000$, the constant of integration = 14,000, $\alpha = 0$, and $\beta = 0$.

Knowing A, N and ω, the necessary E_1 and E_2 are easily computed; a direct-current component of voltage obtained from a battery and variable resistance, both connected in series with the circuit, will be required to supply the IR drop produced by the direct-current component due to the bias term in B, that is, the 14,000 term. The value of the direct current required will not be known until the problem is solved.

FIG. 4.



Output curve with Hipernik core.

Plotting H, point by point, from equation 7 gives the curve of Fig. 4. Since H is proportional to the current in a uniform toroid type of core, changing the scale of ordinates will make this a curve of output current drawn from the line by the coil. The peak at $\theta = 90°$ is due to saturation of the iron by a peak of the flux wave; which corresponds to the 90° point in Fig. 1. Because the constant of integration is chosen large (14,000), the flux is still positive for θ between 40° and 60°, also between 120° and 140°. In Fig. 1, these points have lesser negative peaks, also represented in Fig. 4 by the dips in the curves. In the other half-cycle, two peaks occur, one between 220° and 240° and the other between 300° and 320°; these similarly correspond to Fig. 1. In between these last two peaks the

negative peak of Fig. 1 corresponds to a valley in Fig. 4. The presence of even harmonics in Fig. 4 should be noted. The average value of H to be maintained by the battery is 12.3 oersteds; the maximum value of the fundamental in 5.82 oersteds; and the r.m.s. value of the wave is 23.3 oersteds. The yield of fundamental component amplitude is 25 per cent. of the r.m.s. value, which is large for a third order effect.

OTHER SYSTEMS YIELDING SUBHARMONICS.

Many other non-linear systems exist, some of which are automatic in their action, such as spark gaps, corona, air films, ionized gas rectifier tubes; others may be controlled by separate excitation, such as the Thyratron. An extreme case consists of a Thyratron-rectifier supplying a Thyratron-inverter in which the output frequency may be as low as desired. Subharmonic production may occur, and perhaps unexpectedly, in many types of electrical apparatus.

The author is indebted to Dean H. E. Clifford and to Professor C. L. Dawes of the Harvard Engineering School for their helpful suggestions in the preparation of this paper.

BIBLIOGRAPHY.

1. C. L. Dawes, P. L. Hoover and H. H. Reichard, "Some Problems in Dielectric-Loss Measurements," *Trans. A. I. E. E.*, 48, 1271 (1929).
2. Ferguson, J. G. and Bartlett, B. W., "The Measurement of Capacitance in Terms of Resistance and Frequency," *The Bell System Technical Journal*, July, 1928, p. 420.

APPENDIX.

Given:

$$\Delta x = E_1 \cos(m\theta + \alpha) + E_2 \cos(n\theta + \beta). \qquad [m > n]$$

By Taylor's Theorem,

$$\Delta y = a\Delta x + b(\Delta x)^2 + c(\Delta x)^3 + \cdots.$$

The first term:

$$a\Delta x = a[E_1 \cos(m\theta + \alpha) + E_2 \cos(n\theta + \beta)].$$

The second term:

$$b(\Delta x)^2 = b[E_1^2 \cos^2(m\theta + \alpha) + 2E_1E_2 \cos(m\theta + \alpha)\cos(n\theta + \beta) + E_2^2 \cos^2(n\theta + \beta)]$$

$$= b\left\{E_1^2\left[\frac{1 + \cos 2(m\theta + \alpha)}{2}\right] + E_2^2\left[\frac{1 + \cos 2(n\theta + \beta)}{2}\right] + 2E_1E_2\left[\frac{\cos[(m + n)\theta + (\alpha + \beta)] + \cos[(m - n)\theta + (\alpha - \beta)]}{2}\right]\right\}.$$

On combining,

$$b(\Delta x)^2 = \frac{b}{2}(E_1^2 + E_2^2) + \frac{b}{2}E_1^2 \cos 2(m\theta + \alpha) + \frac{b}{2}E_2^2 \cos 2(n\theta + \beta) + bE_1E_2 \cos[(m + n)\theta + (\alpha + \beta)] + bE_1E_2 \cos[(m - n)\theta + (\alpha - \beta)].$$

The third term:

$$c(\Delta x)^3 = c[E_1^3 \cos^3(m\theta + \alpha) + E_2^3 \cos^3(n\theta + \beta) + 3E_1^2E_2 \cos^2(m\theta + \alpha)\cos(n\theta + \beta) + 3E_1E_2^2 \cos(m\theta + \alpha)\cos^2(n\theta + \beta)].$$

Taking the E_1^3 term alone,

$$E_1^3 \cos^3(m\theta + \alpha) = \frac{E_1^3}{2}[1 + \cos 2(m\theta + \alpha)]\cos(m\theta + \alpha)$$

$$= \frac{E_1^3}{2}\left\{\cos(m\theta + \alpha) + \left[\frac{\cos 3(m\theta + \alpha) + \cos(m\theta + \alpha)}{2}\right]\right\}$$

$$= \frac{3}{4}E_1^3 \cos(m\theta + \alpha) + \frac{E_1^3}{4}\cos 3(m\theta + \alpha).$$

Similarly,

$$E_2^3 \cos^3 (n\theta + \beta) = \frac{3}{4} E_2^3 \cos (n\theta + \beta) + \frac{E_2^3}{4} \cos 3(n\theta + \beta).$$

Continuing with the product term,

$$3E_1^2E_2 \cos^2 (m\theta + \alpha) \cos (n\theta + \beta)$$

$$= \frac{3}{2} E_1^2E_2[1 + \cos 2(m\theta + \alpha)] \cos (n\theta + \beta)$$

$$= \frac{3}{2} E_1^2E_2 \cos (n\theta + \beta) + \frac{3}{4} E_1^2E_2 \cos [(2m + n)\theta + (2\alpha + \beta)] + \frac{3}{4} E_1^2E_2 \cos [(2m - n)\theta + (2\alpha - \beta)].$$

Similarly, with the other product term,

$$3E_1E_2^2 \cos (m\theta + \alpha) \cos^2 (n\theta + \beta) = \frac{3}{2} E_1E_2^2 \cos (m\theta + \alpha) + \frac{3}{4} E_1E_2^2 \cos [(2n + m)\theta + (2\beta + \alpha)] + \frac{3}{4} E_1E_2^2 \cos [(2n - m)\theta + (2\beta - \alpha)].$$

Combining into a final formula,

$$\Delta y = \frac{b}{2} (E_1^2 + E_2^2) + \frac{3}{4} cE_1E_2^2 \cos [(2n - m)\theta + (2\beta - \alpha)] \quad 0 \& 1$$

$$+ bE_1E_2 \cos [(m - n)\theta + (\alpha - \beta)] \quad 2$$

$$+ aE_2\left[1 + \frac{3}{2}\frac{c}{a}\left(E_1^2 + \frac{E_2^2}{2}\right)\right] \cos (n\theta + \beta) \quad 3$$

$$+ aE_1\left[1 + \frac{3}{2}\frac{c}{a}\left(\frac{E_1^2}{2} + E_2^2\right)\right] \cos (m\theta + \alpha) \quad 5$$

$$+ \frac{b}{2} E_2^2 \cos 2(n\theta + \beta)$$

$$+\frac{3}{4}cE_1^2E_2\cos[(2m-n)\theta+(2\alpha-\beta)] \quad 6\,\&\,7$$

$$+bE_1E_2\cos[(m+n)\theta+(\alpha+\beta)]$$

$$+\frac{c}{4}E_2^3\cos 3(n\theta+\beta) \quad 8\,\&\,9$$

$$+\frac{b}{2}E_1^2\cos 2(m\theta+\alpha)$$

$$+\frac{3}{4}cE_1E_2^2\cos[(2n+m)\theta+(2\beta+\alpha)] \quad 10\,\&\,11$$

$$+\frac{3}{4}cE_1^2E_2\cos[(2m+n)\theta+(2\alpha+\beta)]$$

$$+\frac{c}{4}E_1^3\cos 3(m\theta+\alpha) \quad 13\,\&\,15$$

The numbers following each line denote the order of the harmonics for $m = 5$, $n = 3$.

Non-Scuffing Shoes.—A report from the Mellon Institute of Industrial Research, states that plans are being made for an extensive series of tests on the wearability of a "Vici Special" leather developed for a leather concern in Philadelphia. This new leather needs no dressing in the shoe factory or while in service, as it will polish by simple rubbing, after cleaning with soap and water. By a radically different tanning process, it is permanently lubricated by an impregnation which supports the fibers against fatigue and adds to the beauty of colors by creating a fuller and softer tone. The leather is waterproofed without interference with the natural breathing qualities.

The scuffing resistance was measured by a drum apparatus that throws shoes loaded with sandbags violently against the abrasive and drum. Rated on the basis of the number of scuffs, area scuffed and depth of disfigurements, this new leather was given a mark of 95 as against 70, 60, 60, and 40 respectively for four others. Other physical properties of Vici Special are being studied.

C.

An Optical Bench.—It has been brought to our attention that a manufacturer of scientific instruments has evolved a new optical bench which represents a revolutionary improvement in design and manufacture, permitting it with its accessories to be offered at prices easily within the reach of the average industrial laboratory, high school, or college. With it almost every conceivable experiment in optics can be performed, either by individuals or as a classroom demonstration. Accessories are provided for experiments in reflection, refraction, diffraction, polarization, telescopy, microscopy, photography, spectroscopy and so on.

C.

Dangerous Eyelash Dye.—The Federal Food and Drug Administration has issued an emphatic warning against an eyelash dye sold under the name of "Lash-Lure." According to the *Journal of the American Medical Association*, this product contains an aniline dye which is extremely corrosive and capable of burning away the outer coating of the eyes. A prominent clubwoman of an Ohio town was recently made totally blind as a result of an application, administered by a beauty parlor operator, of this highly poisonous cosmetic.

C.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

INTERNATIONAL COMMITTEE AND GENERAL CONFERENCE ON WEIGHTS AND MEASURES.

The International Committee on Weights and Measures held its regular biennial meeting at Paris, September 26 to October 11, 1933. A General Conference is convened only at intervals of six years; the eighth Conference met on October 3, 4, 6, and 10, 29 of the 32 member nations being represented. The delegates of the United States were Prof. A. E. Kennelly of Harvard University and Dr. Theodore Marriner, Counselor of the American Embassy at Paris.

Members of the International Committee are elected as individuals rather than as representatives of countries. Professor Kennelly was elected provisionally by the International Committee last year to succeed the late Dr. S. W. Stratton, and was regularly elected by the General Conference on October 10.

The official record of the 1933 meetings will not be issued for some months; the following information regarding actions of the General Conference is abstracted from reports of the delegates.

Thermal Expansion of Prototype Meters.—New determinations have shown that the equations adopted by the first General Conference in 1889, as expressing the relation between length and temperature for certain prototype meter bars, were not exactly correct. Consequently the Eighth Conference canceled the old certificates, so far as these equations are concerned, and authorized the International Committee to furnish new formulas based upon the later measurements at the International Bureau of Weights and Measures. (Data furnished informally by the International Bureau indicate that the new certified values of the bars belonging to the United States will show much better agreement with the relative lengths as measured at the Bureau of Standards than was obtained by using the original certificate.)

* Communicated by the Director.

Definition of the Meter in Wave-lengths of Light.—The British delegate proposed that the conference adopt the principle of defining the unit of length by means of light waves instead of the present prototype meters of platinum-iridium. If the meter were so defined, the yard might be likewise expressed in wave-lengths. This would give an opportunity to fix the ratio between the two units definitely and permanently, and at the same time to reconcile the small difference now existing between the *legal* yards of Great Britain and of the United States. (In industrial practice British and American units have been made alike by adopting the relation 1 inch equals 25.4 millimeters.)

On the advice of the International Committee, however, the Conference agreed only to recommend further study of this question, without committing itself to the adoption of wave-lengths as the basis of measurement.

International Scale of Temperature.—The General Conference accepted some corrections to the text defining the temperature scale provisionally adopted by the 1927 Conference (see *B. S. Jour. Res.*, Vol. 1, p. 635, October, 1928; Res. Paper No. 22), but decided to convoke an International Conference on Thermometry before adopting the temperature scale as definitive. Questions regarding the use of thermocouples and optical pyrometers, and regarding the variation of the boiling point of water, were also referred to this proposed special conference.

Advisory Committee on Photometry.—The Conference approved the organization of a new committee to advise the International Committee on Weights and Measures on photometric standards and systems of measurement. It will be similar to the existing Advisory Committee on Electricity, being set up in accordance with the following resolution:

> This Advisory Committee shall be limited to ten members and shall be composed:
>
> (1) of a representative of each of the National laboratories designated by the International Committee;
>
> (2) of specialists designated individually by the International Committee.
>
> As president of the Advisory Committee the International Committee will designate one of its own members.

In order to assure the collaboration of the eminent personnel of the International Commission on Illumination, the specialists appointed as members of this new Advisory Committee shall be chosen with due regard to the composition of the Special Committee on Units and Standards of the above Commission.

Establishment of a Standard of Light.—It is expected that a black-body radiator will be adopted eventually as the fundamental standard of light, and a resolution was proposed setting forth the necessity of fixing the brightness of such a radiator at some color-temperature near that of carbon-filament lamps. This requirement would be fulfilled by a radiator controlled by freezing platinum. The Conference, however, decided to leave the formulation of specifications in the hands of the new Advisory Committee, and after some discussion adopted the following resolution:

The General Conference, while supporting the opinion expressed in 1930 (by the Advisory Committee on Electricity, approved in 1931 by the International Committee) that the primary unit of luminous intensity ought to be based upon the radiation of the black body, believes that it would be premature to adopt specifications for this standard at the present time.

The Conference therefore gives to the International Committee the power to fix the specifications for the standard of light at a suitable time after receiving the advice of the Advisory Committee on Photometry, and to take such measures as are necessary to make the specifications effective.

Substitution of Absolute Electrical Units for the Present "International" Units.—In accordance with recommendations of the Advisory Committee on Electricity and of the International Committee (see Technical News Bulletin No. 152, December 1929, and No. 191, March, 1933), the following resolution was adopted:

The Conference sanctions the principle of the substitution of the absolute system of electrical units for the international system, but since some national laboratories have not yet completed the measurements needed to show the relation of the international units to the absolute units, it decides to postpone until 1935 the provisional establishment of the ratio between each international unit and the corresponding absolute unit.

The Conference gives to the International Committee the powers to fix these ratios then without waiting for another Conference, and also to fix the date for adoption of the new units.

The delegate of Belgium stated that his country had already adopted a law prescribing the use of the absolute units.

Jurisdiction over Electrical Units.—Questions having been raised regarding the authority of the General Conference to change the fundamental electrical units, the Conference adopted a resolution declaring itself the legal successor of the London Conference of 1908 on Electrical Units and Standards and delegating to the International Committee full powers to change the specifications adopted by that Conference when necessary.

As will be seen from the above summary, the General Conference dealt only with organization and general principles to be followed in establishing international standards. The detailed work is done by the International Committee through its advisory committees and the International Bureau of Weights and Measures, in collaboration with the national standardization laboratories. More specific decisions on technical questions will therefore be made by these agencies in accordance with the powers conferred by the General Conference.

DISSOLVING RHODIUM-PLATINUM ALLOYS FOR ANALYSIS.

Ignition of a mixture of rhodium with sodium chloride in an atmosphere of chlorine has been recommended by several authors as a means of attacking this refractory metal prior to refining operations. There has been no suggestion, however, that this treatment is satisfactory for the quantitative solution of rhodium or rhodium-platinum alloys for analytical purposes. In the course of analyzing some alloys containing 50 to 60 per cent. of rhodium, it was found that this method of attack was surprisingly effective. Rhodium forms a readily soluble double chloride, Na_3RhCl_6. Platinum forms the soluble salt $NaPtCl_6$, which, however, is less stable toward heat and may be partially decomposed at the temperature necessary to form the rhodium compound.

The alloy was rolled into a thin ribbon, cleansed with hot concentrated hydrochloric acid, and cut into small pieces. A known quantity of the alloy was mixed with 3 to 4 times its weight of sodium chloride and placed in a porcelain boat. The boat was placed in a combustion tube where the salt mixture was gradually heated to incipient fusion in a slow

current of chlorine. The product of the reaction was dissolved in water and filtered. The filter was not washed at this stage but was returned to the beaker and treated with diluted aqua regia to dissolve a small amount of metallic platinum. The resulting solution was filtered and the filter and paper pulp washed thoroughly with hot water. The filter was strongly ignited in a porcelain crucible and the small residue subjected to a second treatment with sodium chloride and chlorine. The crucible was covered with a Rose lid of quartz, and chlorine was introduced through a quartz tube. The salt mixture was finally just melted. No residue of platinum nor of rhodium remained after this treatment.

The reaction with sodium chloride and chlorine may be conducted entirely in a crucible, but if this is done it usually is necessary to repeat the treatment a third time.

EFFECT OF HEAT TREATMENT ON THE EXPANSIVITY OF A PYREX GLASS.

By the use of heat treatments at different temperatures between 450° and 750° C., it has been found possible to change the mean linear expansivity of a pyrex glass between 20° and 200° C. to the extent of more than 10 per cent. The expansivity of the specimen in its original condition was approximately 0.0341×10^{-4} and after treatments near 750° C. this was increased to 0.0345×10^{-4}, while treatments at 450° C. reduced it to 0.0307×10^{-4}. After any such change the original expansivity could be restored by a heat treatment near 650° C. Treatments between 650° and 450° C. appeared to reduce the expansivity rather steadily as the treating temperature was lowered.

These results indicate that there is a real advantage in annealing this glass at the lowest practical annealing temperature, especially if a minimum expansivity is desired. A reduction of 10 per cent. in this coefficient, for example, should increase the resistance of a glass to heat shock and this is one of the characteristics to be desired in general service glass wares. For a more complete account of this work Research Paper no. 626 in the December number of the Bureau of Standards Journal of Research should be consulted.

COMPARISON OF AMERICAN AND ENGLISH CHINA CLAYS.

Samples of some American kaolins have been electrodialized for the purpose of estimating the quantity of < 0.6 micron material by the water adsorption method in a manner similar to that reported for English kaolins in Technical News Bulletin no. 186 (October, 1932). It is interesting to note that if the milliequivalents of bases in the clays are calculated from their chemical composition, the amounts of these bases removed by electrodialysis are approximately as follows:

Clays.	Approximate Amount Removed, Per Cent.
13 English china clays—primary	5–18
American kaolin R—primary	12
American kaolin S—primary	22
American kaolins T, U, V, W, Z—secondary	100
American kaolin X—secondary	60
American kaolin Y—secondary	47

This would indicate that most of the bases in the English clays and in the two primary American clays R and S are held in the form of stable minerals such as the feldspars and micas, the relatively small remainder being present in the adsorbed form. Practically all the bases present in the pure secondary American clays, T, U, V, W, and Z are held in an adsorbed condition. However, only about one-half are so held in the clays X and Y, which are relatively impure. The second half are present in the micas and possibly "clay minerals" (montmorillonite).

It would appear from the above that if the mineral constituents of a clay are to be studied by calculation from chemical compositions, more accuracy would be gained by analyzing the electrodialized clay rather than the raw or untreated.

OLIVINE AS A REFRACTORY.

Olivine, a silicate of iron and magnesium, is a greenish, transparent to translucent mineral usually occurring in granular aggregates or as small disseminated, glassy grains. Large quantities of this material are available in North Carolina and some speculation has arisen relative to its suitability as a special refractory. Since olivine is fairly rich in magnesium,

and if it should prove to be basic or semi-basic in character its use in certain metallurgical operations where magnesite brick is employed at present may be feasible. This applies especially to its use in industries along the eastern seaboard, since magnesite must be shipped from either the west coast or imported. Very little information relative to the properties of this material was available; consequently a short study of those properties which would aid in the classification of the material was undertaken by the Bureau.

Olivines representing three different deposits in North Carolina and one each in California, British Columbia, and Russia were tested. The chemical analyses were obtained on the raw material, the linear thermal expansion, pyrometric cone equivalents (softening points), specific gravities, and petrographic analyses on both the raw material and material heated at 1,400° C.

The chemical analyses show the silica to range from 40 to 45 per cent., magnesium oxide 40 to 49 per cent., iron as ferrous oxide 7 to 15 per cent., with lesser amounts of alumina, calcium, and titanium. The rate of linear thermal expansion was fairly regular from room temperature to 900° C., except for a slight irregularity between 200° and 300° C., and again between 650° and 700° C. The total expansion was somewhat lower than that of magnesite. The specific gravity ranged between 3.206 and 3.434, and was as a rule higher after heating than before. The P. C. E. (softening point) ranged from 30 (1,650° C.) to above 35 (1,785 + ° C.), except the ore high in calcium oxide which had a P. C. E. varying between 11 and 16 (1,325–1,465° C.). The olivines from North Carolina were more refractory than those from the other sources.

The results indicated that an olivine from North Carolina was sufficiently refractory to temperature and to certain slags to warrant classifying it as a so-called special refractory. Bricks made from run-of-mine material gave satisfactory results in the few physical tests to which they were subjected.

NOMOGRAM FOR DETERMINING THE PRESSURE OF ATMOSPHERIC WATER VAPOR AND RELATIVE HUMIDITY.

In the course of an automotive research at the Bureau, it was necessary to determine the pressure of atmospheric water

vapor frequently. The customary double interpolation in tables was found slow and productive of errors; hence a nomogram was developed for estimating the pressure of water vapor from psychrometric observations. It was subsequently found that by addition of two scales to the original nomogram relative humidity also could be accurately evaluated.

It has been found that use of these charts increased the precision and halved the time required, in comparison with use of tables. Hence they have been made available in printed form as Miscellaneous Publication no. 143, copies of which may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

REVISED REPORT OF NATIONAL SCREW THREAD COMMISSION NOW AVAILABLE.

A revised report of the National Screw Thread Commission, superseding the last previous report, published in 1928, has just been issued as Miscellaneous Publication no. 141 of the Bureau of Standards. Progress in screw thread practice between 1928 and 1933 made necessary several revisions and some additions to the standards set forth in the 1928 report. These changes include: The addition of five sizes to the coarse and one to the fine thread series; the elimination of all sizes above 1½ inches from the fine thread series; the elimination of the small machine screw sizes from class 4, close fit; the addition of four sizes to the hose-coupling threads; the revision of gage tolerances for pipe threads and class 4, close fit; and the revision of the specifications for Acme threads. The fine series is supplemented by a new 8-pitch, a revised 12-pitch, and a new 16-pitch thread series. The recommended practice for threading tools has been deleted from the appendixes, but references are given to published standards for such tools.

The initial standardization of screw threads in the United States was carried out by a special committee appointed by The Franklin Institute in 1861, and which made its report in 1864. This report recommended the adoption of a thread system designed by William Sellers, and which finally became known as the United States standard thread. Among other things, the adoption of this standard was a great boon to American

railways, in the development of which it has played an important part. While the United States standard thread system fulfilled a great need in the period of rapid expansion of our railway systems, it did not meet all the requirements of modern industries. To satisfy these needs other systems having smaller sizes and finer pitches have been developed, notably by the American Society of Mechanical Engineers and the Society of Automotive Engineers.

The War made necessary the purchase by the Government of vast quantities of threaded parts from many different manufacturers, and called to the attention of Congress the necessity for a single body having the power to investigate and promulgate standards of screw threads to be adopted by manufacturing plants under the control of the Army and Navy, and for adoption and use by the public. The result was the National Screw Thread Commission, originally authorized by Congress for a period of six months, beginning July 18, 1918. The life of the commission was several times extended, and by act of Congress passed April 16, 1926 it was made permanent. However, the commission was abolished by Executive Order signed June 10, 1933. Under the Act of 1926 the commission consisted of nine members, one of whom was the Director of the Bureau of Standards, as chairman; two representatives of the Army; two of the Navy; and four appointed by the Secretary of Commerce, two of whom were chosen from nominations made by the American Society of Mechanical Engineers, and two from nominations made by the Society of Automotive Engineers. The members of the commission served without compensation and the expense of publishing any necessary reports was borne by the Department of Commerce.

The present publication is, thus, the final report of the commission representing the culmination of 15 years of effort. It should prove invaluable to engineers everywhere. Copies are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents each.

Breaking Crude Oil-Water Emulsions.—Water emulsified in crude oil is a source of trouble to the oil producer. Most oil wells sooner or later produce water-in-oil emulsions which become more difficult to break the longer the well has been producing. Such variation in the type of emulsion necessitates corresponding alterations in the methods for breaking them. Heating the oil is the general method of removing water. Field studies showed that at some wells it was necessary actually to boil the water out of the oil because the emulsion was so difficult to break, while at other wells the emulsion broke very easily at temperatures about 130° F. At some wells it was the practice to pass the oil through a heater; the emulsion at other wells could be broken by bubbling the oil through warm salt water.

At the request of a large oil concern, a company manufacturing radiators has developed a new and efficient heater for demulsifying petroleum. To meet practical requirements the heater must be gas-fired; so designed that it can be assembled and knocked down easily in the field as well as the parts readily moved from place to place; its throughput must be increasable at the will of the operator; it must be efficient on widely different methods of removing water; and must consist of a very limited number of castings. All these requirements have been satisfied.

C.

Tilted Eggs—Live Chicks.—The Bureau of Animal Industry points out that the improper tilting of the eggs in the incubator trays is responsible for half the hatching failures. Dr. Byerly's experiments indicated that losses from abnormal positions of chicks in the shell may be reduced though not entirely eliminated. An incubator tray was devised that maintains a position between the horizontal and 45° angle. The eggs were turned mechanically every 15 minutes and rotated on their long axis in an arc of 60° to 120° but were never rolled over and over. Eggs that were turned always in the same direction every 15 minutes showed a very heavy loss.

Other factors also control the hatchability of eggs. Losses may be reduced by giving careful attention to the diet of the breeding stock and by selection of the breeders. Milk products are considered the best sources of protein concentrates for a flock of breeders, although a mixture of milk, meat scrap, and vacuum-dried white fish products also give good results.

C.

NOTES FROM THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

HOFFMAN STOSSE AND THE ORIGIN OF COSMIC RAY IONIZATION.

BY

W. F. G. SWANN.

It is generally recognized that whatever may be the nature of the primary cosmic radiation, the actual rays which play the rôle in our experiments are charged particles. We are familiar with the existence of groups of charged particles in cosmic ray phenomena. These groups seem to divide themselves into two more-or-less distinct categories, that involving a few rays, and larger bursts of rays known as Hoffman stosse, in which hundreds and even thousands of charged particles may be emitted. The number of these Hoffman stosse emitted per unit *volume* per unit time from solids seems to depend little upon the atomic number.[2] In other words it is the *number* of the atoms in a given volume rather than their weight which is significant. It is the purpose of this letter to point out that an appreciable part, and possibly nearly the whole of the observed cosmic ray intensity may be attributed to bursts of the Hoffman stosse type in the atmosphere. Only in the case of a burst originating very near the apparatus will more than a single ray enter the apparatus, so that the observed characteristics of such rays will be those of single rays occurring at random.

Let q be the number of stosse emitted per second per atom. If q is proportional to the intensity I of some radiation, a photon component of the cosmic radiation, for example, and if subscript s refers to the earth's surface, $q = q_s I/I_s$.

It may readily be proved that the atmosphere may be replaced by its homogeneous water equivalent in all matters except that the number of stosse emitted per cc. of the equivalent water atmosphere must be taken as Nq_s, where N is the number of atoms of air in one gram of air.

Consider the contribution of the stoss particles which are emitted downwards in a solid angle $1 - \cos\theta_0$, determined by a polar angle θ_0 measured from the vertical. As a first approximation, let the particles be emitted uniformly in this solid angle and let n be their number. The number reaching the ground within the solid angle, and coming from the element of volume of unit horizontal area and thickness dh at the altitude h in the homogeneous atmosphere is $nNIq_s/I_s$ if $R > h/\cos\theta_0$, $nNIq_s(1 - \cos\theta)/I_s(1 - \cos\theta_0)$ if $R < h/\cos\theta_0 < R/\cos\theta_0$, and zero if $h > R$, R being the range of the particle in water, and θ being given by $\cos\theta = h/R$ for $\theta < \theta_0$.

The total number of stoss particles reaching each square centimeter of the earth per second from solid angles determined by θ_0 is, on the average, equal to the total number of this class contributed to the whole earth's surface per second by a vertical column of unit cross sectional area extending to the top of the atmosphere and this is $J(\theta_0)$, where

$$J(\theta_0) = nNq_s\int_0^{R\cos\theta_0}\frac{I}{I_s}dh + \frac{nNq_s}{1 - \cos\theta_0}\int_{R\cos\theta_0}^{R}\frac{I}{I_s}(1 - h/R)dh. \quad (1)$$

It will suffice,[1] as a first approximation, to assume $I/I_s = e^{\mu h}$, where μ is an apparent coefficient of absorption related to the true coefficient of absorption appearing in Gold's formula and calculable from it for limited ranges of h. With this understanding, and with H written for $R\cos\theta_0$

$$J(\theta_0) = \frac{nNHq_s}{\mu H}\left[\frac{e^{\mu R} - e^{\mu H}}{R\mu(1 - \cos\theta_0)} - 1\right]. \quad (2)$$

N has the value $N = 4.1 \times 10^{22}$. For q_s, we have such data as that obtained by Steinke and Schindler, and by Montgomery and the writer. According to the latter data, there is a production of about 1×10^{-8} stosse per cc. per second in iron at the surface of the earth. This gives $q_s = 1.16$

[1] Strictly speaking one should consider each initial direction of the radiation separately in its capacity of producing a shower within an angle θ_0 about it as axis. The correction involved is small, however, particularly in a calculation which concerns itself only with orders of magnitude.

$\times 10^{-31}$. Since $e^{\mu R}$ and $e^{\mu H}$ really represent respectively the ratios of the production of stosse per atom at altitudes R and H to that at the surface of the earth; and since R and H are the logs of these corresponding ratios, formula (2) really gives $J(\theta_0)$ in terms of *experimental* measurements of the variation of rate of production of the large stosse with altitude, without even any implication as to their origin from photons. Only the exponential law is involved. Unfortunately, there is no data on variation of the large stosse with altitude sufficiently complete for the purposes of direct calculation. Pending the accumulation of such data, we are driven to make some hypotheses as to the production of the stosse founded upon their relation to cosmic ray intensity. It has been suggested by Steinke [2] that the softer photon components of the cosmic radiation are mainly responsible for the production of the large stosse. At first sight such a view is at variance with the idea that the stosse arise from the transformation of the energy of the photon into positive and negative particles. For a stosse giving even 100 rays of energy 10^9 volts would require a photon of energy 10^{11} volts to produce it. The older theories which attributed cosmic ray photon absorption to the extra nuclear electrons would have prohibited the association of a 10^{11} volt photon with the softer components of the cosmic ray photons; and, while absorption theories have had to suffer changes in the light of the now known importance of the nucleus in such phenomena, one hesitates to take advantage of the slackening of the control of those theories to make assumptions which might well be vetoed by their successors. If, however, we assume that the energy of the stoss comes from a single atom, we are again in difficulty; for, the complete annihilation of the mass of an iron atom, for example, would provide only about 5×10^{10} electron volts energy; and, for lighter atoms, the amount would be proportionally smaller. Then, as pointed out by Montgomery and the writer,[3] the number of particles emitted in a large stoss is larger than that contained in any single atom. A way out of some of these difficulties is suggested by some recent experiments of G. L. Locher made in this

[2] E. G. Steinke, A. Gastell, and H. Nie, *Naturwiss.*, **21**, 560, 1933.

[3] *Phys. Rev.*, **44**, 52, 1933.

laboratory. As a result of observations on cloud photographs of stoss particles, Locher has been led to conclude that many atoms may participate in the production of a shower through the intermediary agency of neutrons. If we add to this conclusion the supposition that the stoss particles and their energy come from the atoms, we are able to invoke the energy of many atoms to account for the stoss and such a view enhances the probability that the initiation of the act of production of the stoss may come about through the agency of a soft photon. We shall investigate the consequences of assuming for the true coefficient of absorption of the radiation concerned the value 0.0055 per cm. of water quoted by Millikan [4] as the coefficient for the radiation which is responsible for 90 per cent. of the cosmic ray ionization in the atmosphere. The μ in our formula is obtainable from this as an approximation and comes out as $\mu = 0.012$ between sea level and an altitude of 250 cms. in the homogeneous water atmosphere. We shall consider, tentatively, a range of 250 cms. for R.

According to some unpublished measurements of C. G. Montgomery, at least 100 particles are emitted within a cone of vertical angle $\pi/4$, i.e. $\theta_0 = \pi/8$. Inserting these values, and the values of N and q_s already given, we find, for this case, which we shall call case 1,

$$J(\theta_0) > 6.8 \times 10^{-4}. \qquad \text{Case 1}$$

If we should assume that the particles are emitted in the whole angle $\pi/2$ with the same solid angular density as that with which they are emitted in the $\pi/8$ angle, we should have [5] $n = 100/(1 - \cos \pi/8) = 1300$. Under these conditions, we find

$$J(\theta_0) > 0.32 \times 10^{-2}. \qquad \text{Case 2}$$

[4] *Phys. Rev.*, 44, 246, 1933. It is realized that to the extent that the photon radiation originates outside the atmosphere, very little of this soft radiation could penetrate to the earth; and the value is used merely by way of illustration. As will be seen later, a value one-fifth this amount, or even a value zero still leaves the stoss particles a potent agency in contributing to the cosmic ray intensity.

[5] Stosse containing as many as 4000 rays have been reported by Steinke (reference 2), and Montgomery has observed stosse with 3000 rays in this laboratory.

From measurements of Johnson and Street, the number of cosmic ray particles given by Geiger counters as passing through one square centimeter of the earth's surface per second is 1.2×10^{-2}. It will be seen that the value of $J(\theta_0)$ for Case 2, amounts to one-quarter of this value. A total emission of 5000 stosse particles would be sufficient to make $J(\theta_0)$ equal to the cosmic ray intensity.

Perhaps one of the weakest points in the foregoing development lies in the assumption of such a large value for μ. However if, retaining the other hypothesis of Case 2, we take $\mu = 0.003$ which represents a true absorption coefficient of 0.0011, and corresponds to the experimental data for the total radiation for the lowest 2 meters of water equivalent of the atmosphere, we still find $J(\theta_0) > 0.10 \times 10^{-2}$ which corresponds to ten per cent. of the measured cosmic ray intensity at the earth's surface. Even the assumption $\mu = 0$, which amounts to assuming no increase of stosse emission with altitude gives $J > 0.08 \times 10^{-2}$. An increase in the value of R would enhance still further the value of $J(\theta_0)$. We are limited here, however, by the fact that the range of the particles must not be assumed so great that appreciable fractions of them come from altitudes comparable with the total height of the atmosphere as such an assumption would result in a variation of cosmic ray intensity with altitude which was inconsistent with the facts.

The main purpose of this note is not to insist on any specific values of the quantities taken for illustration in the calculation, but merely to call attention to the order of magnitude of the effect of these stoss particles in contributing in appreciable amount to the observed cosmic ray intensity as obtained by Geiger counters.

SWARTHMORE, PA.,
October 26, 1933.

Deadly "Rods" of Derris Powder.—(U. S. Department of Agriculture Clip Sheet No. 801.) Derris powder is deadly to the cattle grub but considerable difficulty is encountered in getting the powder into contact with it living beneath the hide of a cow's back. A most effective method of making this necessary contact is to prepare a mixture of an ounce of derris powder, ¾ ounce of gum arabic, ¼ ounce of glue and ¼ ounce of tannic acid powder. Add enough water to make a stiff paste and roll into slender rods, which become brittle when dry.

The treatment consists of inserting the rod into the hole through which the grub entered the hide, and breaking it off at the surface of the skin leaving the opening effectually plugged with a small section of the rod. This kills the grub and has proved much quicker than older methods.

C.

Employees' Ideas Effect Economies.—The Pennsylvania Railroad reports that during the past six years 11,233 suggestions for improving service and operations have been sent in by the employees. Many of the suggestions have proved practical and to be of real value. In 1908, when the "Bureau of New Ideas" was established, 9.2 per cent. of the suggestions received were adopted in whole or in part, while in the first ten months of 1933, 40.4 per cent. of the suggestions finally acted upon were adopted.

C.

THE FRANKLIN INSTITUTE

THE HISTORIC FRANKLIN INSTITUTE.

MEETING HELD EIGHT FIFTEEN O'CLOCK P.M.,

THURSDAY, NOVEMBER TWENTY-THIRD, NINETEEN HUNDRED AND THIRTY-THREE.

HALL OF THE OLD FRANKLIN INSTITUTE,

FIFTEEN SOUTH SEVENTH STREET.

On the night of November twenty-third the Institute held its final meeting in the old building. The program arranged for the occasion was designed primarily to point out all the important contributions of the Institute to the welfare of the city and to scientific advancement.

The program carried out follows:

Presiding Officer
The President of the Institute, MR. NATHAN HAYWARD
"A Few Remarks of Welcome" . . . . . MR. HAYWARD
"The First Half Century". MR. ALFRED RIGLING, *Librarian*
"Personal Experiences in The Franklin Institute"
MR. SAMUEL M. VAUCLAIN
"Experiences in the Schools of the Institute"
MR. JAMES G. MORGAN
"What The Franklin Institute Meant to Me"
MR. EDWARD G. BUDD
"The Future of the Institute"
By its Secretary and Director, DR. HOWARD MCCLENAHAN

A complete report of the proceedings of this meeting follows:

MR. HAYWARD:

The meeting will please come to order. I have much pleasure in presenting to you the first speaker of the evening,

a man whom you all know and who has done much for The Franklin Institute, Mr. Rigling.

MR. RIGLING:

Mr. Chairman, Members of the Institute, Members of the Alumni Association, Friends:

I suggested to Dr. McClenahan that I might be able to refresh your memories on the beginnings and early days of the Institute, not because I was present during that memorable period, but because I was able to form contacts and make acquaintances in my youth with gentlemen who were active in promoting the affairs of the Institute during the first half century of its existence or who had information not otherwise available. I recall Frederick Fraley, John Sartain, Frederick Graff and Hector Orr.

Mr. Fraley became a member of the Institute as soon as it was founded and was active in its behalf during his entire life—a period of seventy-five years. He served on the Board of Managers and for thirty-four years was Treasurer. He was a member of City Councils for a time and also served as a state senator. He was one of the founders of the National Board of Trade and the Union League. The Centennial Exhibition of 1876 had his active support and he was treasurer of its Board of Finance.

Mr. Sartain, a native of London, came to Philadelphia in 1830 and introduced the mezzotint to this country. He was proprietor and editor of *Sartain's Union Magazine* and a benefactor of Edgar Allan Poe. He is known throughout the world as an artist and engraver. Among his most noted engravings are "Christ Rejected," "The Iron Worker and King Solomon," "The Battle of Gettysburg" and numerous others. He was head of the Department of Art of the Philadelphia Centennial. He lived nearby and was an almost daily visitor at the Institute.

Frederick Graff, civil engineer, a native Philadelphian. His father designed and constructed the first water-works of Philadelphia and was its chief engineer for many years. Young Graff succeeded his father as chief engineer and served about fifteen years. He was the first to suggest the establishment of a park on the banks of the Schuylkill—the beginning

of Fairmount Park. He was a member of the Institute for fifty-one years, for a time a member of the Board of Managers and for three years a vice-president.

Hector Orr, Scotchman by birth, Philadelphian by choice, was present as a young man on that February evening in 1824 at the County Courthouse. He was a printer by trade, became a member of the Institute in 1837, and continued with the Institute throughout his entire life—a period of more than fifty years. For sixteen years he was a member of the Board of Managers (1871–1887). When not in his printing shop he was in the Institute's library.

To these gentlemen and many others I am indebted for what I know of the Institute's early history.

It is needless to recount the trials and tribulations of Samuel Vaughn Merrick and William Hypolitus Keating, the two young men who conceived the idea of founding a technical society. We know they succeeded, and as evidence of this fact we find that on December 9, 1823, a meeting was held in the hall of the American Philosophical Society by a group of about a dozen gentlemen, among them Mathias W. Baldwin, Samuel V. Merrick, James Ronaldson and William H. Keating. At that meeting it was deemed expedient to form a Society for the Promotion of the Mechanic Arts. A committee was appointed to draft a report on a constitution, call a future meeting and invite such persons to attend as might be interested.

The committee lost no time in carrying out its instructions and a meeting was called for the evening of Thursday, February 5, 1824, in the County Courthouse. A large and enthusiastic gathering of citizens was present on that occasion; Mr. James Ronaldson was made chairman and Mr. Merrick, secretary.

It was resolved that the best mode of obtaining the objects sought by the founders would be by the establishment of popular lectures, by the formation of a cabinet of models and minerals and of a library, and by offering premiums on all useful improvements in the mechanic arts. The following gentlemen were elected to the respective offices:

James Ronaldson, President,
Isaiah Lukens and Matthew Carey, Vice-Presidents.

Among the managers were:

Robert Patterson, President of the Mint,
John Haviland, architect,
John Price Wetherill, paint and color manufacturer,
Joseph Cloud, refiner at the Mint.

The details of organization proceeded immediately.

A committee was appointed on February 16th to memorialize the legislature for a charter. On the 26th of February the memorial was presented in the Senate and House. The act to incorporate the Institute was passed by the legislature and signed by the governor on March 30th.

The several standing committees were active while the memorial for the charter was being considered at Harrisburg. A committee on lectures was appointed on March 4th, which immediately made arrangements for courses of lectures on chemistry and other subjects. It was decided that Dr. Patterson should inaugurate the first course, but a day prior to the time scheduled for the lecture Dr. Patterson found it impossible to complete his plans and Professor Keating took his place. This lecture was given in the Academy on Fourth Street below Arch, which was placed at the disposal of the Institute by the Board of Trustees of the University of Pennsylvania. The subject of Dr. Patterson's lecture was "Perpetual Motion," a problem which is as fascinating today as it was a century ago, and no nearer solution.

The fact that the Institute was without a permanent home made little difference. The management continued with its plans for an exhibition of American manufactures to be held on October 18th, 19th and 20th, and a drawing school for members' sons and apprentices which was scheduled to open early in October.

Right here we might pause a moment to record that on April 1st Mr. E. I. duPont, powder manufacturer, was elected to membership, and on this same date Mr. Oliver Evans was admitted. Five gentlemen were appointed at this same meeting to act as a Committee on Library.

In October three very important steps were taken. The drawing school was opened, the first exhibition of American manufactures was held in Carpenters Hall, and arrangements

were completed for obtaining a permanent home. The drawing school was opened with fifty pupils. Mr. John Haviland, architect, was in charge of the school with Mr. Hugh Bridport as an assistant. Mr. Bridport was a miniature painter of note and an excellent specimen of his work is on display in the library. It is a portrait of Professor Keating. The drawing school flourished for ninety-nine years.

The exhibition was also a success. It was the first devoted to American products and while it was held in the little hall of the Carpenters Company, it meant much to the many infant industries. We find the following note in the report of the Committee on Exhibitions:

> "Your committee beg leave to call attention of the Board to a clock invented by Joseph Saxton and exhibited by Philip Garrett. . . . The 'scapement is new, ... The friction of this clock is so much diminished as to require no oil on its pallets. Your committee, therefore, recommend that the Silver Medal of the Institute be awarded to Joseph Saxton for his newly invented clock."

Joseph Saxton, American mechanician, watchmaker, printing press constructor and newspaper publisher. He invented a machine for cutting teeth of wheels. He was an excellent draftsman and engineer. He became associated with Isaiah Lukens, another mechanician of note—both members of the Institute. Saxton visited England, where he became a sensation. Michael Faraday introduced him to the Royal Institution and he exhibited, before the British Association for the Advancement of Science, a magneto-electric machine, with which he showed a brilliant spark, decomposed water, exhibited the electric light between charcoal points, and gave a rapid series of intense shocks. He was a prolific inventor in many fields; even a fountain pen is to his credit. He was tendered the office of director of the printing machinery of the Bank of England but declined this offer in order to accept, in 1837, that of constructor and curator of the standard weighing apparatus of the U. S. Mint in Philadelphia.

At the first exhibition there were shown two pianos, one a square piano of the first class, remarkable for its beauty and its pleasing tone, made by Messrs. John and Thomas Loud of Philadelphia, and another made by William Geib of New York, of common English construction, neat and pretty, its tone

remarkably brilliant. No awards were recommended for these instruments because they were not entered for competition.

The Institute's exhibitions did much for American manufactures, especially for chemical industries and the musical instrument manufacturers. The piano industry received much encouragement. Daniel Spillane in his History of the American Pianoforte, its technical development and the trade, published in 1890, contains the following dedication:

> "To The Franklin Institute of Pennsylvania, which has exercised such a potent influence upon the early history of the American pianoforte and the kindred arts, this work is respectfully dedicated."

James M. Swank in his "History of Iron in All Ages" also expresses his appreciation of the value of the Institute's exhibitions.

The third important step taken in October 1824 was announced in the third quarterly report of the Board made to the Institute on October 21st. A contract had just been concluded with the Carpenters Company for rental of the whole of the building known as "Carpenters Hall" at the rate of $500 per year. By subletting the second story it was hoped the expense would be reduced to $225. A hall so central and so adequate for the various purposes of lecturing, holding the collections of the Institute, offering a suitable place for the meetings of the Board and of the Society at large could not have been obtained on easier terms. The Institute occupied these quarters for one year and four months.

After obtaining possession of Carpenters Hall, the several committees became still more active. Mineral cases were erected at once, the cost of the first exhibition case being contributed by the President of the Institute and at his request was devoted to specimens of minerals from Delaware County. Attempts were also made to display the books which formed the nucleus for the library.

Early in 1825 "Proposals for the Exhibition of 1825" were made public. The list of premiums, which included four gold, sixty-three silver and fifteen bronze medals was published at the same time.

The fact that the Institute was now permanently located at 320 Chestnut Street meant very little to the Board of

Managers and the active members and within a few months after they were established, there were demands for a new building. In May 1825 it was voted to erect a building. This site was purchased for $9,000. It covers 60 feet on Seventh Street and 100 feet to a rear alley. The plans submitted by John Haviland were approved. The cost of the building was estimated at $24,000. Thirty-four thousand dollars worth of stock was issued at 5 per cent. premium, payable half yearly and redeemable October 1st, 1840. It is interesting to note that this agreement was fully carried out; no stock was outstanding in 1841.

The *United States Gazette* of Wednesday, June 8, 1825, contained a brief notice of the laying of the corner of the building which was to take place on that day at noon. Peter A. Browne, a noted attorney, Chairman of the Building Committee, delivered an address. His remarks were lengthy and I am able to quote only two paragraphs:

> "There is no person who reflects beyond the present moment who would not desire that this institution should be placed upon such a basis as will ensure its benefits to our children, and as nothing will be more likely to guarantee its permanency than a fixed place of meeting, deposit and exhibition, the building of this Hall will, I am confident, be considered a subject of sincere public congratulation.
>
> "As it will be erected principally by the mechanics of Philadelphia, it will no doubt be considered as a specimen of their taste; great care will therefore be taken by the building committee to maintain a corresponding character. Like that highly useful class of the community, it should be distinguished not so much by ornament, as purity of design and solidity of construction."

The corner stone contains the constitution and by-laws of the Institute, the first annual report, three medals, a half-dollar, a ten cent piece and a three cent piece of the coinage of 1825.

When the Institute invaded this neighborhood, it was still a residence section. Only one business was in the block—a druggist's shop, conducted by Mr. John Gardom, adjoining the building on the south. This was a real chemist's shop; there was no counter devoted to stationery and perfumes; sandwiches and coffee were not to be had. Mr. Gardom was a good neighbor and a loyal friend. The announcement from one of the newspapers confirms this statement. He lived next door for sixty-three years.

Lecture on the Steam Engine.

FRANKLIN INSTITUTE.

PROFESSOR JONES will on Wednesday the 13th inst. and also on Friday, the 15th inst. deliver a lecture on the Steam Engine, at 8 o'clock, in the evening. A perfect working model will be exhibited, and such other experimental illustrations given, as will render its structure, and mode of operation, clear to every person.

Tickets, admiting a gentleman and lady, or two youths, 50 cents; to be had of Mr. Gordon, Druggist next door to the Institute, or at the door of the Lecture Room.

Managers of the Institute admitted without tickets.

June 12—taw&f

In the fall of 1825 the second exhibition was held, this time in Masonic Hall, Chestnut Street above Seventh. The exhibits were more numerous and the quality of the products improved. Ten exhibitions were held in Masonic Hall, and the next twelve in the Philadelphia Museum Building, northeast corner of Ninth and Sansom Streets.

The twenty-fifth exhibition was held in Dr. Jayne's building on Dock Street. In 1858 the State Armory Building and adjacent grounds at Sixteenth and Filbert Streets were used for the twenty-sixth exhibition. Sewing machines were the most important single exhibit and a report especially on these was published in the same year.

No exhibitions were held between 1858 and 1874 because it was found impossible to obtain suitable buildings. In the latter year the Pennsylvania Railroad Company abandoned its freight station at 13th and Market Streets and the Institute was permitted to use it for its twenty-seventh and most successful exhibition—the forerunner of the great Centennial of 1876.

The International Electrical Exhibition of 1884 and the Novelties Exhibition of 1885 still linger in the memory of many of us.

In the fall of 1826 the Institute opened its High School under the direction of Walter R. Johnson, with 304 pupils: 300 were studying English, 153 French, 105 Latin, 35 Greek, 45 Spanish, 20 German, 300 elocution, 240 geography, 231 linear drawing and all of them mathematics. You will note that the newspapers were conservative even at that early date. This school was continued until the Board of Educa-

(From the Philadelphia Gazette of September 15, 1826.)

"THE High School of the Franklin Institute.—We understand that, in consequence of the great number of applications for admission to the institution, beyond what can be received with the present arrangement, it is intended to open a new department as soon as the necessary accommodations can be prepared."—National Gazette.

We sincerely hope that before a new department is opened time will be allowed to test the excellency of the system that has been adopted. Three hundred and four boys are quite enough to make an experiment upon, and, if the experiment should chance to fail, what compensation can the proprietors of this new establishment offer to society for the evil done in breaking up the private schools.

tion established the high school as a part of the city's system of public instruction.

In 1850 the Committee on Instruction submitted a report to the Board of Managers on Mrs. Sarah Peters' suggestion to establish a School of Design for women. Early in the following year the Institute leased rooms for the school on Walnut Street west of Third and two years later the school became a separate organization.

The Institute has done much work of public importance. In 1829 a committee was appointed to investigate the efficiency of moving water as a motive. Seven hundred experiments were conducted with water wheels of every type and publication of the results of these tests was not completed until 1841.

In 1830 another investigation was undertaken into the probable causes of accidents on steamboats. At the request of the Secretary of the Treasury of the United States the Institute's investigation was extended to include the explosion of steam boilers and the strength of materials. The committee found it necessary to devise its own apparatus for the testing of metals, building materials, steam boilers and so forth. The investigation covered a period of seven years.

In 1833 the Institute was requested by the State Legislature to report upon the weights and measures of the state. A committee of seventeen was appointed to consider the matter. The extensive report which included a detailed statement on the weights and measures of France, England and the United States, as well as an authentication of the Troy pound used in the United States Mint appeared in the JOURNAL of the Institute for November 1833 and February to July 1834. The present laws of the state are based on these investigations.

A joint committee of The Franklin Institute and the American Philosophical Society began systematic meteorological observations in aid of agricultural and other interests in 1834. This work was continued for four years when the American Philosophical Society withdrew and remaining members of the committee continued as the Institute's Committee on Meteorology.

In 1843 City Councils requested information on the best modes of paving highways. A sub-committee of eight members of the Committee on Science and the Arts was at once appointed. A voluminous report was soon presented which treated all phases of the subject, and recommended pavements most suitable for Philadelphia.

A uniform system of screw threads, bolt-heads and nuts for the use of American engineers was presented in December 1864. This system was adopted by the U. S. Government in 1868 and is known as the Sellers of Franklin Institute system.

The solar eclipse of 1869 visible at Mount Pleasant, Iowa, was observed by a special party of twenty volunteers under the direction of Dr. Henry Morton, then secretary of the Institute.

In the same year, 1869, a committee of three was appointed to memorialize Congress in reference to an exhibition to be held in Philadelphia on the centennial anniversary of American Independence. City Councils and the State Legislature became active in behalf of the project and in 1871 Congress passed an act which provided for the observance of this event by an international exhibition.

A special committee began an investigation into the modes of determining the horse-power of steam boilers in 1871. The final report of its findings was not published until two years later, December 1873.

Suggestions made at the monthly meeting held on February 19, 1873 resulted in establishing the Second Geological Survey of Pennsylvania.

The report of the Committee on the Causes of Conflagrations and the Methods of their Prevention with an exhaustive paper on "The Light Petroleum Oils" considered as to their safety, or danger, in various domestic uses, were published in April 1874.

Twice, in 1875 and 1882, the Institute was invited to take part in investigations of the pumping stations and reservoirs of the water department and the problem of the future water supply of the city.

The first tests of dynamo electric machinery ever made in the world were undertaken by the Institute in 1877. Professors Thomson and Houston conducted the experments.

In June 1825 the Board of Managers appointed a committee of five known as "The Board of Examiners" which was directed to examine and report upon new inventions. This body later became the Committee on Inventions with Isaiah Lukens as its first chairman. In 1834 the Committee was again reorganized and has been known since that time as the Committee on Science and the Arts.

It is a unique group of specialists with no counterpart anywhere in the world. Since its last reorganization in 1834 the Committee has examined and reported upon 2,976 inventions.

The *American Mechanics' Magazine*, the first publication of its kind in this country, made its appearance in New York in January 1825.

The management of the Institute, feeling the need for a means of communicating its activities to the world, purchased the magazine during the early part of the summer. Announcement was made in August that the FRANKLIN JOURNAL and *Mechanics Magazine*, under the patronage of the Institute, would appear shortly.

Dr. Thomas P. Jones was editor of the *Mechanics Magazine*. He came to Philadelphia to continue as editor after the Institute had taken it over. He was appointed recording secretary of the Institute and curator of its collections. In 1828 he was made superintendent of the Patent Office by

Henry Clay and held the office until 1836. His interest in the Institute's JOURNAL continued until his death in 1848.

The first number of the FRANKLIN JOURNAL was published in January 1826; it contained 60 pages of reading matter with illustrations.

One of the interesting contributions, though short, was from the pen of William Strickland, civil engineer, and the most noted native architect of his time. It is entitled "A Description of the Hetton Rail Road in England," and is accompanied by a folded engraving of the railroad and its equipment.

The JOURNAL has appeared uninterruptedly since January 1826, for some years as a sixty-page monthly, followed for another and greater period at eighty pages per month, and in more recent years at about one hundred and forty pages per issue. Volume 216 will be completed in another week.

Mr. Chairman, my time is up but my subject is not exhausted. I shall close with a few lines from a poem, written in 1874, by a member in commemoration of the Institute's fiftieth anniversary:

> "The iridescent rays of scattered power,
> Our Institute collects and concentrates,
> Then sends them forth in scientific phalanx,
> To conquer nature and to bless mankind.
> This was the high ambition of its founders
> Who (like the steward in the parable)
> O'er the few things allowed them have been faithful,
> May those who follow have the full 'ten talents,'
> And well improve the new and larger trust."

MR. HAYWARD:

I think that Mr. Rigling has given us a real message, a message which we should all take home with us, to make us realize our responsibility to the Institute of the future. If you will review the paper of Mr. Rigling, there are several things that particularly stand out in the history of the Institute. When there was a need of something to be done, the Institute did it. It was in the Institute that the electrical unit was determined upon; it was in the Institute that the first tests of boilers was made—the Institute did that kind of work when there was no one else to carry it on. They did it so well that

they could not stop. One outgrowth from such work was the Bureau of Standards. The work is now done by the United States Government. The Institute began the work and then turned it over to someone else. Again, there were the schools, mechanical drawing and engineering. In this field the Institute did a tremendous work. When the public schools began to incorporate such subjects into their curricula, the Institute turned the work over to them; and so on through the history of this old society. It fills a need but is perfectly willing to step aside when other institutions become equipped to handle the business.

Our next speaker is a man whom we all so respect for his ability and integrity that it is hard to find anything new to say of him. He has always been, and still is, our very good friend—Mr. Vauclain!

MR. VAUCLAIN:

I was asked to address this audience for ten minutes. One cannot say much in ten minutes, if you are going to think, therefore, what I am going to say to you is simply that which occurred in this hall many years ago and which left an indelible impression on my mind.

An inventor usually has a hard road to travel and when one had to go up against The Franklin Institute's Committee on Science and the Arts, his task was a hard one. He had to convince that Committee that he was really an inventor of the device for which he claimed an award, and that award was much sought after at that time, namely: the Elliott Cresson Gold Medal. It was not very large but probably had more gold in it than the American dollar of today.

My impressions were due to the experience of having invented a compound locomotive. Everyone said it would not work, that I was wasting my time. Still, I didn't waste any time because I got orders from first one and then several and they came along much faster as the months rolled on. Therefore, we knew this, that this locomotive was a workable machine. The idea was original and was proven to be original after many months of investigation. I cannot tell you how many anxious hours I put in before that Committee, month after month, before the award was made, but if today you look around this building and you notice the paintings of men on

the walls, after careful study is made of them you will find why The Franklin Institute is here today. They were the men of brains of the city—workers, manufacturers of all lines of business, from pianos down to the insignificant locomotive!

Then there is another thing about awards. It is very strange. You will get one medal and that ends it. You can come along with thirty or forty more inventions but you will find it very hard to get a medal for these. But there are exceptions. In 1891 I was awarded by this Institute a John Scott Medal and Legacy—a medal for the invention of the new process of manufacturing wrought iron. It was much easier to get that medal because these wheels were being made and they themselves were evidence that the method was correct and the wheels durable.

Well, I was awarded by The Franklin Institute a John Scott Medal, about 4″ in diameter and 3/8″ thick, copper, and with that medal I received twenty dollars. When I put that in my pocket, it felt like a car wheel!

Forty years later, in 1931, this John Scott Medal was again awarded to me—this time by the City Trusts, which had taken over its administration in 1918. For various inventions I was awarded the John Scott Medal and received with it a Premium of one thousand dollars. I was embarrassed. I said 'I do not think I am entitled to this medal because I already have a Scott medal.' They said 'That cannot be!' I showed them the one I had received in 1891. Then they said, 'All right, but you are entitled to another one anyway!' So I took the medal and gave the check for one thousand dollars to the Bryn Mawr Hospital. That only shows how uncertain these things are. You read that the John Scott Medal is given to men of highest attainments: Edison, Marconi—it has been awarded to a host of them.

The Franklin Institute is the founder of all these inventions of today. They blazed the way. The Thomson-Houston people, spoken of by Mr. Rigling, started right here on this floor. Elihu Thomson rose to greatest heights in The Franklin Institute. For his inventions he has profited and has gone out into the world with success.

I want to remind you that when you leave this old building, when you leave all these pictured walls with the pictures of

great men, and go into that mansion on the Parkway, you are going to miss this. You are going to miss this old building and the wholesome and comfortable atmosphere of this strange little room. Don't forget what you have left behind; get a good impression and devote the rest of your life to making the new home of The Franklin Institute as worthy of the Institute as this one has been!

MR. HAYWARD:

The first speaker spoke of the schools which the Institute had. I am going to ask Mr. Morgan, a naval architect with the New York Shipyards, who graduated from these schools and taught in them, to say a few words about them to us: Mr. Morgan!

Mr. Chairman, Ladies and Gentlemen, Members and Friends of the Franklin Institute.

It is with fear and trembling that I approach this part of the program on such a memorable, historic evening as this. It is but reasonable to expect that, in a recital of reminiscences, such as are in order at a meeting of this kind, the personal pronoun will be predominant. I am sure that I will be pardoned therefore, for its extensive use as my personal relations with the Institute are referred to.

Away back, as a boy, my connections were first made with the school. I say away back, yet my associations are modern when compared with the activities of many of those present here tonight.

Having served an apprenticeship in drafting at the Wm. Cramp & Sons Shipbuilding Yards, I presented myself for examination at the Philadelphia Navy Yard to qualify as a ship draftsman. The Commanding Officer presiding at that examination informed me at its conclusion that I lacked certain theoretical knowledge in ship design. He stated that if I promised to attend The Franklin Institute and study its course in Naval Architecture, that he would make a recommendation to the Secretary of the Navy for my appointment as a draftsman. The promise was readily given and enrollment at the School brought me into my first contact with the Institute activities.

In 1914 I graduated and how proud we were as the class sat in this old lecture hall at commencement. I recall sitting directly over there at that aisle and how I nervously descended the steps to receive the diploma from the hands of the presiding officer, Dr. Walton Clark.

Several years later, I was accorded the honor of being appointed as an Instructor in the course of Naval Architecture, from which classes I had graduated. Five years were served in that capacity, concluding with the closing of the Institute School in 1923, after it had functioned for 99 years. So many pleasant memories had bound us to the wonderful old school, that its closing was viewed with mingled sorrow and regret.

An alumni Association of students had been organized in 1908 and membership therein enabled many of us to retain a close attachment to the Institute. The privileges accorded to its members by the Institute are many. I believe I am safe in saying that in no other Alumni could we be accorded the privileges that we find in membership in the Alumni Association of The Franklin Institute. The officers of the Institute invite us to every lecture, exhibition and demonstration conducted under their auspices and their interest in us is deeply appreciated.

One of the outstanding incidents in my life was the privilege of attending, in this hall, the demonstration of the opening of the Trans-Continental telephone line.

Many of you here tonight undoubtedly remember that memorable day. The Institute had arranged for several demonstrations at 2, 4, 6 and 8 P.M. as I remember, and I stood outside of the hall for an hour before admission was gained. Every chair in this old hall was equipped with a telephone headset and what a thrill we enjoyed as we placed the phones to our ears. The operator in charge, standing here at this table, then successively took us step by step from one city to another until we were listening to the band playing in the Cliff House on the shores of the Pacific on the west coast. What a miracle we considered that to be and what thrills chased up and down our backs, as we sat on South Seventh Street in Philadelphia and listened to the actual roar of the Pacific and heard the band playing in San Francisco. I shall never forget that evening as long as life shall last.

Another incident that stands out in my experience was the reception given to that venerable inventor, Mr. Thomas Edison. Our Alumni membership was invited to be present and again what a thrill it was to meet and shake hands with such a distinguished gentleman.

It is with a tinge of regret that we say farewell to this old hall and its walls full of pleasant memories. I would like to think of the transition from this building to that on the Parkway as being similar to the passing of one year into a new one.

In the spring, seedlings are planted and break through the ground. In the summer the flowers break forth into bloom, bouquets are gathered and their fragrance spread far and wide. Winter comes and they fade away, but we know the new year is close at hand when once again we will enjoy the beauties of nature.

In 1824 and 1825 the Institute planted its seeds here in the spring of its life. Its summer came along and the flowers commenced to burst forth in their glory. Bouquets were gathered and disbursed and the fragrance of some of these have been passed along again tonight by Mr. Rigling in his recital of the events in the first fifty years of the life of the Institute. Tonight we are in the winter period of the Institute's life in this old building. So we say, with some sadness, Farewell fruitful old year in the life of The Franklin Institute. We then turn and look with gleaming eyes to the building on the Parkway and say Happy New Year Franklin Institure. May it be of longer duration and more beautiful fruition than that which has passed.

MR. HAYWARD:

The next speaker is almost as well known to everyone in the Institute as Mr. Vauclain, and I can assure you fellow members and people who have spent the hours between three and four in the morning, thinking of this place, that he is a philosopher and friend whom I rely on and get help from: Mr. Budd!

MR. BUDD:

When Dr. McClenahan asked me to speak a few minutes on happenings at The Franklin Institute in the early days of

my membership, the ready flow of recollections connected with my early experiences here prompted me to give an assent.

When I began to count back the years, I was appalled by the number, and felt as though I was building among my associates a reputation for age which my temperament and vigor does not justify. I want to make to my associates an explanation of how it could be that I remember so far back.

The story is told of a youthful looking woman who had to tell her friends that she was a grandmother. She was proud of the fact but embarrassed as to her age. She explained—You remember that my daughter was married when very young, and I was married when very young.

I suppose in telling you of my experiences in this old hall, so far back as 1890, I must explain that I started young.

I expect I shall raise some ghosts here tonight. The hall did not look so old fashioned in those days. The main entrance, as I recall, was broad, and the stairways were broad. I remember we considered it an exceptionally well built hall because of the steep slope of the floor, so that those at the extreme back could see the demonstrations which were taking place on this stage.

Among the men who gathered here in those days there were original thinkers. I recall that the question of ventilation was agitated, and some of our distinguished men put a gas flame in the two radiators which you see on the walls to hasten the movement upwards of the currents of air, and thus induce a ventilation of the room. This is the beginning, so far as my knowledge goes, of air conditioning as we see it today.

We had at that time and in active association here, the great names in the scientific and academic world of

Elihu Thomson
Edwin J. Houston
Lewis M. Haupt
John C. Trautwine, 2nd
William D. Marks
Prof. H. W. Spangler

We had the great names of the highly trained technicians

who took a place in the manufacturing world, each the founder of a great business:

William and Coleman Sellers
William B. Bement
Wilfred Lewis
Frederick B. Miles
Alfred C. Harrison
Edwin Harrington
Jacob Naylor
G. Morgan Eldridge

and the Cramps, Fitlers and Disstons.

Mr. Rigling was the energetic, ambitious and kindly librarian who was willing to talk to and assist a boy who was seeking information. The great library that is now being transferred to our new building, he then considered to be a great institution, and he has been adding to its greatness year by year in the interval. Is he not a man to be envied in that he has devoted a life to the building of a storehouse of information which will serve generations to come?

Dr. Wahl was our active Secretary, doing the work that Dr. McClenahan has carried on so successfully in the last few years. He, too, was a man highly trained in scientific matters and with supreme devotion to the interests of the Institute.

In my early youth I was honored by being asked to write an article for the FRANKLIN INSTITUTE JOURNAL, and I recall vividly the educational advantage that came to me through my contact with Dr. Wahl in connection with that article.

My first contact with the Institute was as a student in drawing—two nights a week. I started my work as an apprentice machinist at a quarter to seven in the morning at Bement-Miles & Co. and closed at six at night, came to the Institute at seven and worked until nine in the drafting room. Mr. William H. Thorne was the Director. He was a skillful draftsman, a well educated engineer, and a superior character. I knew nothing of the program or the customs of the school. I did my best to learn as much as I could. The $5.00 fee was quite a tax on me. At the end of the first session in February, this charming gentleman, William H. Thorne, stopped

at my drawing board and said that I had won a prize and that the prize consisted of free tuition for the next term. Seldom has anything happened to me that meant more than this unexpected prize. A year later, still working on without any particular expectation of reward, I completed two drawings, one of the design of a quarter turn belt, and the other of a bevel gear involving the contour of the teeth. The Institute at one of its exhibitions at the Academy of Fine Arts used this bevel gear layout as part of their exhibit.

The school and the library and lectures meant much to the young men at the time. These recollections stand as evidence of the soundness of the school and the wisdom of the management. How many years have elapsed since then and how many students successively have had experiences like mine?

There were keen minds and earnest students in those days in the field of arts and industry. How many of us realize that through the work of

William B. Bement
William and Coleman Sellers
Brown and Sharpe in Providence
Pratt and Whitney in Hartford

the entire industry of tool building was developed in this country. How much we treasured this art, and how keen was our ambition to take each successive step in the advance of our art. Machine tools were developed in this country by that group of men almost simultaneously with the development in England by Whitworth. I recall when the argument over the development of the spur gear was at its height. It was debated in these halls by our seniors and listened to eagerly by us juniors. Some of you perhaps will recall that the Sellers group favored the involute tooth and how the Bement organization advocated the epicycloidal tooth as theoretically more correct. The juniors in the Sellers organization would announce that unless the gear centers were perfect the epicycloidal gear was imperfect and the involute tooth would still be effective even though the centers were incorrect. We boys at Bement promptly announced that we made our centers right, and carried on the argument with

vigor. It was almost like a snowball fight as regards the enthusiasm of the organization.

Then came the question of cutting the tooth. A fierce argument over whether a cut tooth was as good as a cast tooth, and the earnest contention of Southwark and other foundries that they could cast teeth just as well as we could cut them. In my earliest recollections, almost all the teeth were cast, but the gear cutters were coming into prominence. Spur gears were cut by milling cutters, and with considerable accuracy, but I smile to myself to remember how long we used to spend in filing the teeth on the head of a lathe before we let it go out of the shop.

Then grew up a master mind among us. Hugo Bilgram. A highly educated mathematician, a man of tremendous mental alertness, of insistence and persistence, contentious in all matters and meddling in everything from engineering to politics and speculation on this world and the next. A social reformer. He first conceived the shaping of bevel gears and then the generating of the teeth, which led up to the astonishing accuracy which is attained today in the manufacture of gears. He has been the father of gear cutting in America, and it is hard to conceive how an automobile could ever have been completed without this development.

A few years before Wilfred Lewis had led in this Institute a committee appointed by the Institute for the standardization of threads. Threads have been standardized so long that many of us have forgotten the beginning. Long years of painful study were necessary to develop what is known as The Franklin Institute Standard Threads, which has been adopted throughout North America and which has only one rival, the Whitworth Thread in England. I can recall in the old days when we had a bolt without a nut, we would have trouble in finding a nut that would fit it. Nowadays, if a nut comes off a Detroit manufactured automobile in some town in Mexico, you can go to a hardware store and buy a nut you know will fit.

I recall one amusing experience in the early days. There was a strong arm man in Philadelphia who drew large audiences to see him break a cobble stone in two with his fist—and he broke them. A group from this Institute watched him

day after day, and finally Wilfred Lewis discovered the strong man's art and that he, too, could with his fist break a stone in two. He held the stone close to a heavy anvil and then struck it as vigorously as he could with his fist. When the stone struck against the anvil it was broken, not by his fist, but by the anvil.

They were men with alert minds and to whom the laws of nature and physics were an endless fascination, and the solution of the phenomena of these laws was their vocation.

In my earliest day there was still a good deal of talk about the Keeley perpetual motion machine. The detection of this fraud had been previous to my coming to the Institute, but not so far back but that it was still a lively subject of debate here.

I sat in those seats up there and watched the first demonstration of Roentgen rays in Philadelphia. Marvelous, incomprehensible, what developments have come from this discovery of one of the important laws of nature. I looked at it as an excited boy. The men whose names I have given you above, and great numbers of other Philadelphia citizens, gathered as witnesses. The hall was crowded, men standing and sitting on the steps.

I could go on much further. Is it not worth while for us to recall that in the 1890's Dr. Wahl was soliciting funds for a new building, and as a site for the building Alfred C. Harrison was buying residences at 16th and Arch Streets, within a few blocks of our fine new building? Forty years elapsed before the project was accomplished.

There were giants in those days. Their discoveries were great. There is another generation coming up, and we are on the eve of discoveries vastly greater than any we have had up until now. Our children can be and promise to be the giants of a later age, and the years of endeavor and the great liberality of our generation will provide the opportunities for this coming generation.

MR. HAYWARD:

We shall leave this building with sorrow. We shall have a few words now about the future. First, I want to mention one thing. I don't suppose we would be celebrating this meeting it it were not for the work of two or three men, and

I know that the absence of one of those men tonight is a source of sorrow to many of us. The three men I have in mind are: Walton Clark, Mr. Harrison and Mr. Howson, who is with us. I would like to suggest that this meeting order the President to write to the former President of The Franklin Insitute, Dr. Walton Clark, telling him of this gathering and sending him expressions of our affectionate regard.

A motion was made, duly seconded and carried that the President write to Dr. Clark.

MR. HAYWARD:

I present our Secretary and Director, Dr. McClenahan:

DR. MCCLENAHAN:

I have never been a prophet, nor the son of a prophet, but I am going to practice prophecy at this time. When you come to prophesying about mankind, you are dealing with uncertain things. You know already how many untrue things fond grandmothers have uttered about beautiful children! When you are dealing with institutions, language is feeble, expecially about The Franklin Institute.

When I had the pleasure of coming down here in 1925 to take the position which it is now my privilege to hold, two outstanding things became painfully obvious. One, it was very disturbing to see how completely The Franklin Institute had lost touch with the youth of this city, because only two or three years before the schools had been given up and that fruitful source of contact was abandoned and there was no source of contact left. And two, was that here in this building was housed an outstanding library of the physical sciences. It was treated no better than could be expected in such cramped quarters and books were stored everywhere. These two things started the movement which has resulted in our meeting tonight and the migration which began this morning will continue right through until we are really at the Parkway and Twentieth Street.

We wanted to do something that would restore the contact with the youth of the city and we wanted to make our books of the greatest value. We thought about the problem and finally the idea was conceived that we could best reach the young people through the establishment of one of those

great scientific and technological museums, the earliest of which is in Paris and the greatest of which is in Munich. With the guidance and heartiest coöperation of the President of The Franklin Institute, Dr. W. C. L. Eglin, we besought Mayor Kendrick's aid and got the friendly assistance of the City Council, and in 1926 the project which is approaching completion was started. Our purpose was to give service to the youngsters of the community.

Two young men began the Institute. What we are doing now is nothing in the world but an attempt to continue on a different plane; other institutions have come in with more funds and are doing the work which we did, but, as the President pointed out, the Institute has never attempted to carry on work which can be done better by someone else.

Our purpose is the same and so I can predict that the new Institute on the Parkway is going to bring back to us in a way that we have never had, contact with the young people of this city and is going to influence their lives through the opportunities which we are going to give to them to understand and to learn to love the physical sciences.

Our library is going to be housed beautifully, with much room for future growth.

And so I predict that the future of the Institute is that it is going to influence the lives of the young people of Philadelphia through its great treasures of science and that the library is coming into its own.

Another prediction: In this room Elihu Thomson stood at that desk and lectured on induced electrical currents. Through the agencies of our library and our museum such inspiration will come to others and the fame and deservedly high repute of this institution will go on and its influence in the world of science will become greater and greater.

It is with many mixed feelings that we go out of this building, but we go with the utmost resolution that the future of The Franklin Institute shall be even more brilliant than its past, and that its accomplishments shall continue to be evidences of the beauty of the human intellect and for the use and advantage of mankind.

MR. HAYWARD:

This meeting is now dismissed.

PROCEEDINGS OF THE STATED MEETING HELD WEDNESDAY, DECEMBER 20, 1933.

The regular monthly meeting of The Franklin Institute was called to order at eight-eighteen o'clock by the Secretary, Dr. Howard McClenahan, who presided.

He announced that the minutes of the last meeting had been printed in full in the JOURNAL and stated that unless there were objection they would be approved as printed. As no objection was offered, they were declared approved.

The presiding officer referred to the very gratifying increase in the number of applications for membership which had been received and expressed the hope that the new building with its beauty and its fine equipment might attract many people to it and to The Franklin Institute.

He then announced that at this meeting it was necessary to present nominations for the officers and one-third of the members of the Board of Managers whose terms expire at this time and that the names of these nominees will be printed on the official ballot which will be distributed to the membership for the annual election which will be held at the regular monthly meeting in January. He then stated that nominations for any of the offices or for membership in the Board of Managers from the floor were in order, and asked for any such nominations. No such nominations were offered. The list of nominees follow:

Office	*Nominee*	*Nominated by*
President	Nathan Hayward	A. Atwater Kent M. S. Morgan W. Chattin Wetherill
Vice-Presidents	Henry Howson C. C. Tutwiler Walton Forstall W. Chattin Wetherill	George H. Benzon, Jr. James S. Rogers James Barnes
Treasurer	Benjamin Franklin	G. H. Clamer Alfred Rigling
Board of Managers:		
To serve three years:	Francis T. Chambers Charles H. Ewing Samuel S. Fels W. W. Fry Robert W. Lesley Horace P. Liversidge Malcolm Lloyd, Jr. Marshall S. Morgan	Charles E. Bonine Theobald F. Clark Clarence A. Hall

The presiding officer then described the new types of membership which had been established and called the attention of the audience to the application blanks which were on the table. He then made a statement concerning the Christmas Week Lectures which will be delivered on December twenty-seventh and twenty-eighth.

There being no further business the presiding officer then presented as the lecturer of the evening Dr. George S. Crampton, a long time member of The Franklin Institute and a member of its Committee on Science and the Arts, who

addressed the meeting on the subject of "The Manufacture of Ophthalmic Lenses with Special Reference to Modern Bifocals."

Dr. Crampton showed in a very interesting fashion the development of bifocal lenses from the days of Benjamin Franklin until the present time, and showed the characteristics of the several types which have been used. An interesting feature of his talk consisted of the actual grinding of the lenses before the audience. His talk was unusually fully illustrated by experiments and displays of ophthalmic objects.

The meeting was adjourned at ten-eighteen, after an expression of appreciation by Dr. Crampton for all the service which had been rendered to him by various manufacturers and friends, and by a statement by the presiding officer of the meeting's appreciation of Dr. Crampton's delightful effort for their instruction and entertainment.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, December 13, 1933.)

HALL OF THE COMMITTEE,
PHILADELPHIA, DECEMBER 13, 1933.

MR. THEOBALD F. CLARK *in the Chair.*

The following reports were presented for first reading:

No. 2951: Measuring Weight and Moisture Content of Sheet Materials.
No. 2972: Pipe Fitting.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, December 20, 1933.)

FAMILY MEMBERSHIP.

MR. HENRY HOWSON, 123 South Broad Street, Philadelphia, Pa.

LIFE MEMBERSHIP.

MR. ARTHUR H. LEA, Retired, 123 South Broad Street, Philadelphia, Pa.

RESIDENT.

MR. H. P. GANT, Manufacturer, 12 South Twelfth Street, Philadelphia, Pa.
MR. JOSEPH H. HECHT, Certified Public Accountant, Ernst and Ernst. For mailing: 5730 North Howard Street, Philadelphia, Pa.
REV. FRANKLIN JOINER, Rector, St. Clements Church, Philadelphia, Pa.
MISS ANNETTA R. MASLAND, Teacher, Overbrook High School, Philadelphia, Pa.

MR. A. CLYDE SCHOCK, Teacher, Central High School. For mailing: 30 West Evergreen Avenue, Chestnut Hill, Pa.

MR. GEORGE A. SMITH, Patent Lawyer, 2000 Girard Trust Building, Philadelphia, Pa.

MR. WILFRED H. WICKERSHAM, Photographic Department, Engineers Publishing Company, Philadelphia, Pa. For mailing: 324 South Marshall St., Kennett Square, Pa.

STUDENTS.

MR. JULIAN ALEXANDER, JR., 3417 Race Street, Philadelphia, Pa.

MR. DUNCAN ROE DUNN, North Hills Post Office, North Hills, Pa.

MR. DANIEL W. LEWIS, JR., 2111 Hunting Park Avenue, Philadelphia, Pa.

MR. WM. L. ELKINS SINKLER, Elkins Park, Pa.

MR. ROBERT FULLERTON WALK, 517 East Jamestown Street, Roxborough, Pa.

CHANGES OF ADDRESS.

MR. DONALD S. ASHBROOK, Slatersville Finance Company, Slatersville, R. I.

MR. EDGAR W. BAIRD, 420 Edgecliff Road, Dunthorpe, Portland, Oregon.

MR. F. L. DUBOSQUE, 4376 North Bay Road, Miami Beach, Florida.

MR. ARMIN ELMENDORF, 211 East Chestnut Street, Fort Dearborn Station, Chicago, Illinois.

MR. WALTER B. FERGUSON, 1218 Chestnut Street, Philadelphia, Pa.

MR. THOMAS FISHER, 2216 Packard Building, Philadelphia, Pa.

MR. JOHN GRAHAM FOLEY, 267 Ovington Avenue, Brooklyn, N. Y.

MR. E. J. GANGWERE, Assistant Superintendent, Reading Locomotive Shops, 1417 Linden Street, Reading, Pa.

MR. PERCY S. LYON, Commercial Engineering Division, General Electric Company, 570 Lexington Avenue, New York City.

MR. L. W. MACLEAN, Erie Avenue Engine House, Reading Company, Philadelphia, Pa.

DR. J. C. MCLENNAN, Ramsay Lodge, Wentworth, Virginia Water, Surrey, England.

PROF. I. M. RAPP, R. D. 2, Phoenixville, Pa.

MR. SAMUEL SHOEMAKER, G-310 Garden Court Apts., Forty-seventh and Pine Sts., Philadelphia, Pa.

MR. WALTER STEARNS, 4933 Walnut Street, Philadelphia, Pa.

MR. ARTHUR SYNNESTVEDT, 12 South Twelfth Street, Philadelphia, Pa.

DR. EDWARD WESTON, 37 North Mountain Avenue, Montclair, N. J.

NECROLOGY.

Dr. L. Ashley Faught, Philadelphia, Pa.
Dr. Edward Gudeman, Chicago, Illinois.
Mr. William Sellers, Philadelphia, Pa.
Mr. Horace Wells Sellers, Ardmore, Pa.
Mr. Haseltine Smith, Philadelphia, Pa.
Dr. G. Waldo Smith, New York City, N. Y.
General Harry C. Trexler, Allentown, Pa.
Mr. Asa W. Whitney, Bristol, Tennessee.

BOOK REVIEWS.

THE ELECTRICAL PROPERTIES OF GLASS, by J. T. Littleton, Chief, Physical Laboratory, Corning Glass Works, and G. W. Morey, Member of the Staff of the Geophysical Laboratory, Carnegie Institution of Washington. Monograph No. 3, published under the auspices of the Committee on Electrical Insulation, Division of Engineering and Industrial Research, National Research Council. 184 pages, illustrations, 15 × 22.5 cms. New York, John Wiley & Sons, Inc., 1933. Price $3.00.

Five chapters make up this monograph, as follows:

I. The Manufacture, Composition and Properties of Glass.
II. The Electrical Conductivity of Glass.
III. Dielectric Constant.
IV. Dielectric Loss.
V. Dielectric Strength.

Chapter I is concerned with laying a general groundwork for the specialized chapters which follow; it contains about the minimum of information that should be possessed by all having occasion to deal with glass as a material of construction. Useful tables of the compositions and properties of a wide range of glasses are included though less complete than those of International Critical Tables (also from Morey). Among the many surprising characteristics of glass discussed a few may be mentioned: (1) Slight differences in surface conditions possess enormous influence on mechanical strength, evidenced in one way by the increase in apparent strength effected by slight etching with hydrofluoric acid; (2) tensile strength increases rapidly as the cross section is diminished; (3) glass can be considerably strengthened by setting up certain types of internal strain by heat treatment (Littleton and Preston).

Reciprocals of astronomical figures are required to express the conductivities of glasses at ordinary temperatures, yet at fusion temperatures the resistances drop to very ordinary values. It is remarkable that conductivities can be measured at all when the resistances often are of the order of 10^{15} ohm-centimeters. Surface and volume conductivities have to be differentiated and errors of 1000 per cent. more or less must be condoned.

Anomalous charging currents (dielectric absorption), the discovery of which is credited to Benjamin Franklin, are extensively discussed, with particular reference to glass. Enough of the theory of dielectrics is included to make the discussion intelligible as the effects of frequency, temperature, glass composition, surrounding media, etc., are taken up in their relation to dielectric constants, losses and strength.

The authors have reason to and do lament the inadequacy of knowledge in almost every section, Chapter I no less than others. Such literature as exists has been extensively cited. The monograph contributes much to the organization of knowledge of the characteristics of glass which have a bearing on its value as an insulator.

LESLIE R. BACON.

PHILOSOPHY OF SCIENCE, volume 1, number 1, 129 pages, 17 × 25 cms. Baltimore, The Williams and Wilkins Company, 1934.

Before the writer becomes too deeply imbued with his subject, he desires to point out that the task ("pleasure," I should say) of reviewing this premiere issue was suggested to another who gracefully declined on the grounds that he was fairly well acquainted with the Editor. Now you know where we (collectively speaking) stand—or do you?

On behalf of its eventual readers, we extend a hearty welcome to a newcomer, an aristocrat of erudite periodicals, Volume One, Number One of "Philosophy of Science." We congratulate its Editor, William Marias Malisoff, upon the first result of his efforts in this direction. And folks, this is only the beginning, only-the-beginning. Philosophy of Science will be issued every three months.

This writer does not profess to be formal (Is that the word?) or typography conscious, yet when the better half, who has whiled away many a youthful hour reading print upside down, exclaimed over the type (viewed in the reverse) her good taste was conceded by acclamation. Of course the printer's efforts will be wasted if the subject matter is poor. Such is far from being the case. There are articles by such well known scientific philosophers, or are they philosophic scientists, as Carnap, Feigl, Bell, Struik, Malisoff, J. B. S. Haldane and R. A. Fisher. Most of the papers bear an introductory tone, a promise and prophecy of a progressive expansion in Philosophy of Science subjects, of many interesting things to come. Readers of the journal may look forward to a department called: A New Budget of Paradoxes. There will be sections reserved for correspondence, for reviews and for notes.

The high character of this journal may be judged from the fact that all contributions are examined by sub-committees of the editors and members of the advisory board. In general unanimous consent is required to ensure publication.

T. K. CLEVELAND.

TRAVELING WAVES ON TRANSMISSION SYSTEMS, by L. V. Bewley, Power Transformer Engineering Department, General Electric Company, Pittsfield, Mass., 334 pages, tables, illustrations, 15 × 22.5 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., 1933.

Electrical engineers, particularly those occupied with the construction and maintenance of transmission systems, will find this book to be of special value. Written in the interest of the Advanced Course in Engineering of the General Electric Company, the reader will be impressed by its great practical worth. Chronologically speaking, this work is indeed timely, since the theory of traveling electric waves on transmission lines and in transformer windings has undergone extensive developments in the past few years. It has been a worth while effort, this clarification and summarizing of the many theses dealing with cloud discharge and consequent lightning wave formations; transmission and reflection of waves of arbitrary shape; and electrical oscillations in transformer windings set up by impulse voltages.

Sufficient mathematical data are included so as to provide the professional engineer or the student the means for solving transmission lines and machine transients problems. In this capacity the book is also meant to serve as a reference work. To acquire the fullest benefit the reader should have a working knowledge

of operational calculus; however, should such a background be lacking, this prerequisite information will not be difficult to acquire. The author makes no pretense of furnishing a complete bibliography but has furnished a list of those papers most pertinent to the subject.

The book is in two sections: Part One deals with the Origin, Characteristics, and Behavior of Traveling Waves, while Part Two treats of High-Frequency Oscillations and Terminal Transients of Transformers. Starting with the Single-Circuit Theory of Traveling Waves the author develops step by step the transition from the simpler to the more complex waves on multi-conductor systems. Lightning waves are discussed and various methods of protecting the systems discussed.

The author has added greatly to the interest of the book by including a number of cathode ray oscillograms of surges and less powerful electric waves over transmission circuits. The correspondence of these graphically portrayed waves with those derived mathematically is indeed impressive. Another noteworthy feature is the termination of each chapter with an individual summary. An Appendix of 110 hyperboli and allied functions, formulas used in operational calculus, should prove of considerable aid.

T. K. CLEVELAND.

CHEMICAL ENGINEERING CATALOG, 1933 (EIGHTEENTH ANNUAL) EDITION, collected, condensed and standardized catalog data of equipment, machinery, laboratory supplies, etc., with classified indexes, 789 pages, illustrations, 21.5 × 28.5 cms. New York, The Chemical Catalog Company, Inc., 1933.

The Eighteenth Annual Edition of the Chemical Engineering Catalog is now with us. A casual examination indicates that it has been brought thoroughly up to date. A silhouette of the Blue Eagle occupies a prominent position on the "fly" leaf. The section titles seem quite familiar as of old, also the acknowledgments. The Committee repeats its earnest desire to have manufacturers and distributors of equipment, chemicals and raw materials advertise their products still more fully and completely in order that the Catalog may be the "compendium complete." The Information Bureau Service still functions and it would be interesting to know how many subscribers annually avail themselves of its worthwhile benefits.

The Trade Name Index (brought up to date) greets the methodic reader who begins at the front of the volume. Following this comes the Classified Index of Equipment and Supplies. Then comes the list of equipment manufacturers accompanied in many cases with very full descriptive information about their products. It would not be a bad idea to list this section as prescribed reading for all chemical engineering students. Where else could they find such a complete and compact collection of modern chemical manufacturing equipment accompanied by data on characteristics and performance?

The other principal section is that of chemicals and raw materials. The companies listed therein, have furnished very complete lists of their products and in some instances, have included descriptive data which generally is much appreciated. The Catalog is fittingly concluded with an extensive list of technical and scientific books. A subject index makes easy the locating of all current works on any particular subject.

The Committee is to be heartily commended for their ability to maintain the Catalog, particularly during the past few years, with such a large degree of efficiency and completeness.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 460, The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel, by Eastman N. Jacobs, Kenneth E. Ward, and Robert M. Pinkerton, 58 pages, tables, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1933. Price 15 cents.

An investigation of a large group of related airfoils was made in the N. A. C. A. variable-density wind tunnel at a large value of the Reynolds Number. The tests were made to provide data that may be directly employed for a rational choice of the most suitable airfoil section for a given application. The variation of the aerodynamic characteristics with variations in thickness and mean-line form were therefore systematically studied.

The related airfoil profiles for this investigation were developed by combining certain profile thickness forms, obtained by varying the maximum thickness of a basic distribution, with certain mean lines, obtained by varying the length and the position of the maximum mean-line ordinate. A number of values of these shape variables were used to derive a family of airfoils. For the purposes of this investigation the construction and tests were limited to 68 airfoils of this family. In addition to these, several supplementary airfoils have been included in order to study the effects of certain other changes in the form of the mean line and in the thickness distribution.

The results are presented in the standard graphic form representing the airfoil characteristics for infinite aspect ratio and for aspect ratio 6. A table is also given by means of which the important characteristics of all the airfoils may be conveniently compared. The variation of the aerodynamic characteristics with changes in shape is shown by additional curves and tables. A comparison is made, where possible, with thin-airfoil theory, a summary of which is presented in an appendix.

Report No. 470, The N. A. C. A. Tank, A High-Speed Towing Basin for Testing Models of Seaplane Floats, by Starr Truscott, 23 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1933. Price 10 cents.

This report describes the high-speed model towing basin of the National Advisory Committee for Aeronautics, usually referred to as the N. A. C. A. tank. The purpose of this piece of equipment is to enable the Committee to provide information and data regarding the performance of seaplanes on the water analogous to the information furnished concerning the performance of airplanes in the air.

The tank and its equipment, together with the method of operation, are described, and the type of work done in it is illustrated by data from two typical tests. The one was to determine the effect on the take-off performance of a model of the hull of a flying boat of fitting the step with "hooks" of three different

heights, and the second to determine the effect on the take-off performance of the same model of fitting the bottom just forward of the main step successively with two and three flutes of two different depths. In each case the performance with the alterations is compared with the performance of the model with a plain bottom. The distinctive discontinuities found in the speed-resistance curves at hump speed are a notable feature of the results of these tests.

PUBLICATIONS RECEIVED.

The Preparation and Prosecution of Patent Applications, by Charles W. Rivise, foreword by A. D. Caesar, Esq., 484 pages, 15.5 × 24 cms. Charlottesville, The Michie Company, 1933.

Leitfaden der Elektrotechnik, herausgegeben von Dr.-Ing G. Bolz, Dr. Ing. F. Moeller, Dipl. Ing. Th. Werr, Band 1, Teil 1 und 2, 94 pages, illustrations, 16.5 × 23.5 cms. Leipzig und Berlin, Verlag und Druck von B. G. Teubner, 1933.

Funktionentafeln mit Formeln und Kurven, von Dr. Eugen Jahnke, und Fritz Emde, 330 pages, tables, illustrations, 16.5 × 24.5 cms. Leipzig und Berlin, Verlag und Druck von B. G. Teubner, 1933. Price 16 marks.

Introduction a l'Etude de l'Effet Raman ses Applications Chimiques, par P. Daure, 87 pages, illustrations, 14 × 22.5 cms. Paris, Editions de la Revue d'Optique Theorique et Instrumentale, 1933.

Elements d'Optique Geometrique a l'Usage des Candidats aux Grandes Ecoles, par Pierre Copel, 206 pages, illustrations, 14 × 23 cms. Paris, Gauthier-Villars, 1933.

National Advisory Committee for Aeronautics, Technical Notes: No. 477, Aerodynamic Tests of a Low Aspect Ratio Tapered Wing with an Auxiliary Airfoil for Use on Tailless Airplanes, by Robert Sanders, 8 pages, tables, illustrations 20 × 26 cms. Washington, Committee, 1933. No. 478, The Effect of Slots and Flaps on Lateral Control of a Low-Wing Monoplane as Determined in Flight, by Hartley A. Soule and J. W. Wetmore, 11 pages, illustrations, 20 × 26 cms. Washington, Committee, 1933. No. 479, Strength Tests of Thin-Walled Duralumin Cylinders in Pure Bending, by Eugene E. Lundquist, 10 pages, illustrations, 20 × 26 cms. Washington, Committee, 1933. No. 480, The Drag of Streamline Wires, by Eastman N. Jacobs, 7 pages, tables, illustrations, 20 × 26 cms. Washington, Committee, 1933. No. 481, The Reduction in Drag of a Forward-Sloping Windshield, by Eastman N. Jacobs, 4 pages, illustrations, 20 × 26 cms. Washington, Committee, 1933.

CURRENT TOPICS.

Problems in Engineering.—The Engineering Experiment Station, University of Illinois, recently announced the completion of several engineering investigations in diversified subjects, a series that should hold something of interest for a large proportion of the engineering fraternity.

One of these projects, now presented in bulletin form, comprises: "A Study of the Locomotive Front End, Including Tests of a Front End Model." The purpose was to learn the laws governing the production of draft and the movement of air and gases through the front end of a locomotive. Upwards of 3700 determinations were made. For each determination there were recorded the arrangement, the exhaust pressure, the flow of steam, the flow of air, the drafts in front of and behind the diaphragm, the temperatures of steam (at three points) and atmosphere, the wet and dry bulb temperatures as a means of calculation, the humidity, the barometer reading, and such other information as might be pertinent to the phase of the investigation in hand.

In order to clear up a number of uncertainties with respect to brake shoe friction and its variations, the Experiment Station conducted an investigation under the title: The Friction of Railway Brake Shoes, Its Variation with Speed, Shoe Pressure and Wheel Material. Two kinds of brake shoes were tested—the "Diamond S" shoe, used principally on passenger cars, and "Special Chilled" shoes of plain cast iron, representative of many of the shoes used in freight service. Three kinds of tests were made: "Stop tests," which simulate the conditions under which a train is brought to rest; "constant speed tests," in which the speed of the wheel was held constant at some chosen value and the shoe was alternately applied and released, until, in general, ten applications had been made, the duration of each application being 190 revolutions of the wheel; and a "modification" of this test in which the wheel was kept moving at constant speed and the shoe continuously applied to it for fifteen minutes.

The recent development of elevated storage tanks with radial-cone bottoms lends considerable importance to an investigation of: "The Strength of Thin Cylindrical Shells as Columns." The object was to study the type of failure characterized by local wrinkling and to determine the dependence of wrinkling strength

upon variables of two kinds—(1) physical properties of the material and (2) geometrical properties of the cylinder, such as length, thickness, radius, and end conditions. The wrinkling stress indicated by theory was not reached in any of the tests at the failure of the specimen; the highest value obtained was about 60 per cent. of the theoretical.

In connection with some tests on the possible production of low ash and sulphur coal in Illinois use was also made of the X-ray method of coal examination. Pure coal is nearly transparent to X-rays while the common impurities, such as shale, clay, pyrite and calcite are relatively opaque; therefore in an X-ray photograph of a lump of coal, the pure coal substance resembles a block of dirty ice, and any mineral impurities, such as shale, clay, etc., show up as dark to black spots.

The problem of sulfur removal from waste gases still awaits a method of recognized economic feasibility. The washing of large quantities of waste gases with untreated water yet appears too costly. There are possibilities in a catalytic oxidation method for removing sulfur dioxide and work has been started on the development of a regenerative system for recovery, using alkaline reagents.

C.

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